



PROJET D'EXPLOITATION DE LA POTASSE

TITLE:

**Monitoring of Consolidation
of
Waste Salt Backfill**

**Final Report
by
Potash Company of America
Division of Rio Algom Ltd.**

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Abstract

Potash Company of America uses waste salt as backfill for cut-and-fill stoping within a closed loop mining system. The engineering behaviour of the fill is critical since it must fulfil the role of primary ground support as well as meeting the materials balance demands. Backfill consolidation is the most basic variable, from which other properties such as stiffness and strength can be derived. Several instruments were developed for remote monitoring of backfill consolidation; prototypes using tilt sensors, vibrating wire strain gauges and linear potentiometers were all fabricated and tested in a working stope. All instruments functioned well during the limited field trials. A radio frequency transmission system which would allow remote data acquisition through backfill without electrical cables was also designed and a prototype will be tested in the near future.

Résumé

La Potash Company of America utilise des déchets de sel comme matériau de remblayage pour les tranches montantes remblayées d'un système d'exploitation minière en boucle fermée. Le comportement mécanique du remblai est d'importance primordiale car ce dernier doit servir de principal support du sol en plus de répondre aux exigences du bilan des matériaux. Le tassement du remblai est la principale variable de base à partir de laquelle d'autres propriétés comme la dureté et la résistance peuvent être calculées. Plusieurs instruments ont été mis au point pour le contrôle à distance du tassement du remblai. Des prototypes utilisant des capteurs de dévers, des extensomètres à corde vibrante et de l'équipage potentiométrique linéaire ont été fabriqués et mis à l'essai dans une tranche en exploitation. Tous les instruments ont donné de bons résultats au cours des essais pratiques restreints. Un système de transmission par radiofréquence qui permettra l'acquisition de données à distance sur le remblai sans l'utilisation de câbles électriques a également été conçu et un prototype sera bientôt mis à l'essai.

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1. Introduction

Potash Company of America operates a cut-and-fill potash mine at Sussex, New Brunswick which uses salt waste from the mill to fill stopes up to 30 m wide and 120 m high. These stopes are often at low angles (15° to 45°) and adequate compaction under the overhanging walls is difficult to achieve using mechanical equipment. The support provided to the stope walls is highly dependent upon backfill compaction since rapid consolidation of loose fill has been observed to result in loss of contact between the fill and the walls. For economical and safe design of stopes it is necessary that the post-placement behaviour of the backfill (the way in which it consolidates and provides support to the walls) is known with some accuracy.

Instrumentation for remote measurement of the consolidation and pressure in backfill has long been available for use in civil engineering soil mechanics. Typical applications are roadway and dam embankments where access to an exposed surface is permanently available and a secure readout location can easily be maintained after construction is complete. The instruments used in these situations are often not suitable for use in mine backfill because permanent access is difficult or impossible to maintain, conditions are more aggressive because of the mining cycle that must occur between fill cycles and settlements are often more extreme. For these reasons it was felt that it was necessary to develop specific instruments for measuring the properties and behaviour of salt backfill which are of interest in cut-and-fill mining. In the course of this project, several instruments were designed to meet the needs of monitoring backfill in mines. These instruments were used along with conventional commercial instruments to monitor backfill consolidation in a working stope.

2. Backfill monitoring requirements and instrumentation constraints

In cut-and-fill mining the fill has two functions; it provides a stable platform from which machinery can work during the upward progression of stoping and it provides support to the walls of the stope, thus controlling stresses in the crown and caving of the surrounding rocks. For stope design it is necessary to know the stiffness of the fill (its resistance to a change in volume when loaded) and the pressure it applies to the walls at any given time. Fill stiffness is known to be related to porosity which can be deduced from consolidation data if the initial porosity is known. For mine planning purposes it is also useful to know the consolidation of the fill because of its affect on materials balance. The amount and rate of settlement dictates the way in which the demand for fill increases as the stope height increases.

Instruments for measuring the pressure in the fill and between it and the walls are available from geotechnical instrument suppliers. Generically known as earth pressure cells, they have been used previously at PCA and work reliably. The only operational problem with such instruments has been that the cables linking them to the data acquisition equipment is difficult to protect from mechanical damage during the mining and filling cycles. Non-cabled data acquisition would eliminate this serious problem.

One portion of the work reported here was the development of an experimental radio frequency transmission system designed to operate through backfill. The prototypes work only with certain types of instrument but the technology is adaptable to most geotechnical instruments.

The settlement of backfill can be measured using a combination of settlement gauges for vertical movements and tiltmeters for horizontal movements. Civil engineering settlement gauges require access to the edge of the fill mass at the same level as the instrument. This is straightforward for surface structures but is an impractical constraint in many mining situations where access to a particular location is only available as the fill is placed but it is lost thereafter. Likewise, traditional tiltmeters are also impractical because the tiltmeter casing must be extended upwards through the fill as mining is taking place and this invariably leads to damage and loss of the instrument. The approach taken in this project was to develop new instruments which provide the same information but which can be buried in inaccessible locations and monitored remotely, initially through cables and later using the RF transmission system.

3. Instrumentation development

3.1 Radio frequency transmission system

Holohil Systems Ltd. visited the PCA Sussex site to perform tests of RF attenuation in tailings to determine the optimum frequency for a transmission system. Tests were performed in the surface tailings storage shed in order to provide a tolerable working environment for the electronic equipment. Fixed frequency transmitters were buried at different depths in tailings and the signal attenuation was measured at various distances. It was found that the RF signal was masked by approximately 1.5 m of tailings but that if the depth of burial was less, or if there was a length of wire buried near the transmitter to act as an aerial, the signal travelled well across the tailings surface. A 172 MHz transmitter was found to provide the best signal strength and this frequency was chosen for additional trials in a backfilled filled potash stope. The report provided by Holohil Systems Ltd. on transmission tests in tailings is contained in Appendix A.

In the field trial, the transmitter was buried at various points along the top of a stope containing 20 m of tailings and the receiver was positioned in the footwall access ramp. A combination of locations was used in order to test signal attenuation through 0 to 10 m of salt rock and 1.5 to 30 m of salt tailings (see Figure 1). Table I lists the relative signal strengths received in the ramp at various distances from the transmitter.

Based upon these results, Holohil Systems Ltd. has designed and built 4 prototype transmission and receiving units for use with instruments employing either vibrating wire transducers or linear potentiometers. These units were completed at the end of the contract and have not yet been tested in a filled stope. The Richard Branker CL-800 data logger is currently being modified to store data from the radio receivers. Delivery is expected during the next quarter and thorough field trials of the system will be

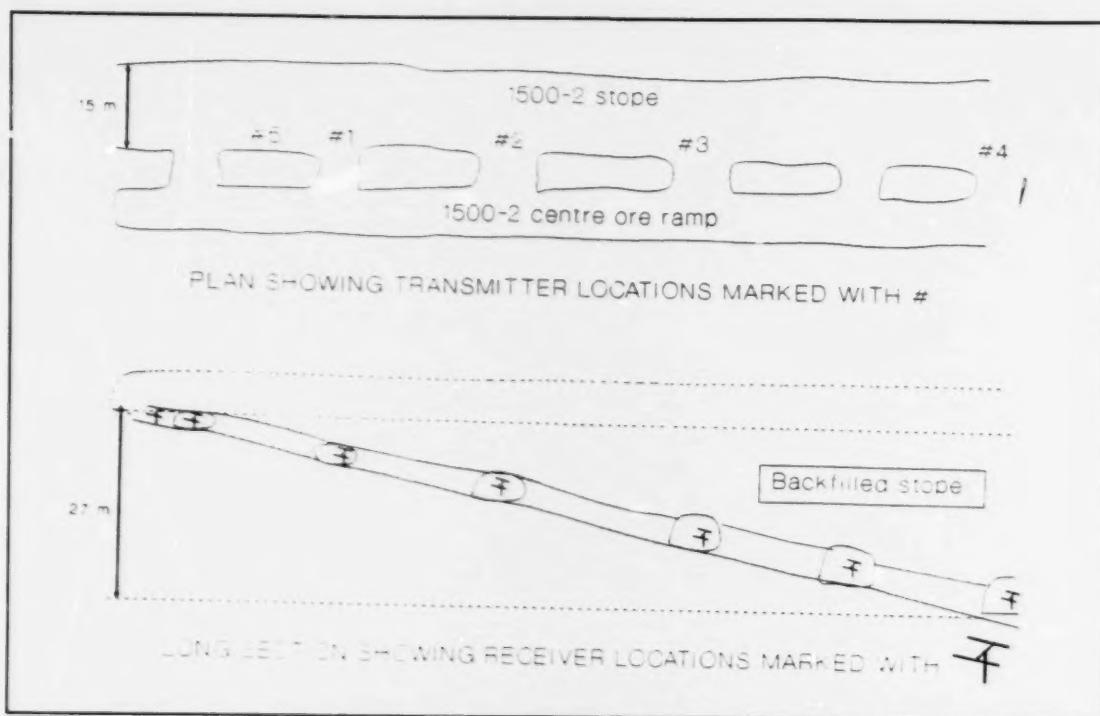


Figure 1 Layout of radio frequency transmission test in potash stope

Table I RF transmission test results from potash stope

Test No.	Transmission medium	Relative signal strength
1	10 m air, 1.5 m tailings	0.7 at 50% gain
2	10 m air, 4.5 m tailings	0.6 at 50% gain
3	10 m air , 10 m tailings	0.6 at 100% gain
4	10 m air, 30 m tailings	barely detectable
5	10 m potash, 21 m tailings	0.4 at 100% gain
6	10 m air, 18 m tailings	0.6 at 100% gain
7	10 m salt	0.7 at 50% gain

undertaken by PCA at the Company's expense.

3.2 Tiltmeters

As discussed previously, mining conditions dictated that a tiltmeter unit had to be self contained and had to be read remotely. To satisfy these constraints, a CANMET design was adopted which called for an Applied Geomechanics Inc. (AGI) two axis tilt sensors (model 757-1138) mounted inside a 46.7 cm long stainless steel tube (see Figure 2). The tilt sensor is mounted on a 45° wedge within the tube so that rotation of the tube about its axis and rotation of the long axis in a vertical plane can be detected. The units are designed to be buried at 45° to provide maximum sensitivity to consolidation (the angle to the horizontal reduces as consolidation takes place). The tiltmeters are connected to AGI model 785 signal conditioning units and a Campbell Scientific model 21X data logger. The system is capable of a resolution of 6×10^{-7} degrees on each tilt axis.

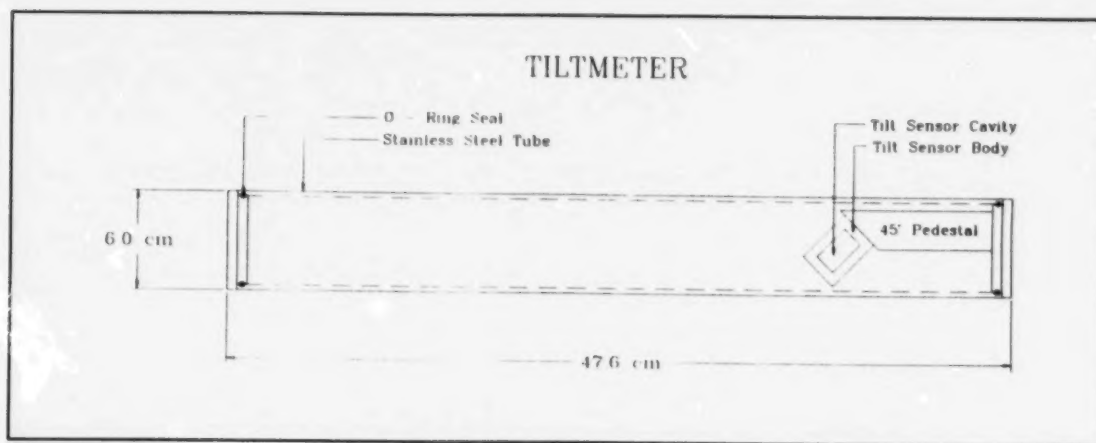


Figure 2 Schematic section of tiltmeter

This system provides benefits other than robustness and resistance from damage. In particular, the capability of continuous logging, not available with tilt casing installations, means that measurements are being taken during the critical times when the mining machine passes above the instrument. Most large fill movements are believed to take place at this time.

A detailed description of the design and operation of the tiltmeter and its logging system is attached as Appendix B.

3.3 Consolidation meter.

A simple consolidation meter was fabricated according to a CANMET design. It employs telescoping copper tubes to activate a linear potentiometer having 100 mm

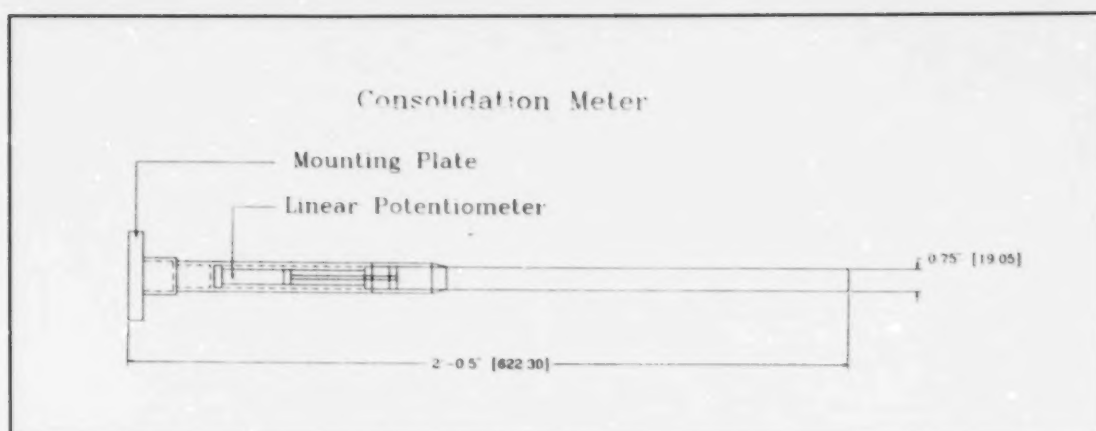


Figure 3 Schematic section through consolidation meter

travel (see Figure 3). The unit can be constructed in virtually any length and is installed in the fully extended state in a drill hole. Compacted tailings have been shown in other studies at PCA to have an extremely high resistance to penetration, so the end of the telescoping copper tube can be pushed to the bottom of the hole, where it seats securely without penetration into the undrilled material. At the top of the hole a 200 mm diameter wooden plate is attached to the end of the potentiometer to provide the top reaction surface. This is required because fresh tailings cannot be compacted directly on top of the instrument.

3.4 Vibrating wire consolidation gauge

A third instrument for the measurement of fill consolidation was based upon the vibrating wire technology used in CANMET Soft Rock Borehole gauges. It consisted of a telescoping rectangular casing which houses two yoke-mounted vibrating wires. It is illustrated in Figure 4. In use, it is installed in a shallow trench cut into compacted fill and then covered with a plywood sheet which spans onto undisturbed fill on either side of the trench. Consolidation of the fill causes the casing to compress the yokes which in turn changes the wire vibration frequency. Branker CL-800 data loggers are used to record the wire frequency at the desired interval. Only one prototype of this instrument was built. In part this was because of the difficulty of sealing it against brine inflow. Also, the inherent stiffness of the instrument introduces the possibility that the instrument partially prevents consolidation and thus measures a composite value of consolidation and overburden pressure. In practice, these problems did not appear to affect the performance of the instruments. This suggests that the consolidation gauge may have more application than was at first expected.

4. Field study of the consolidation of salt tailings

An instrument test site was chosen in one of the shallower potash stopes (the 1500-2 stope, see Figure 5) because of the ease of access for running data cables and the

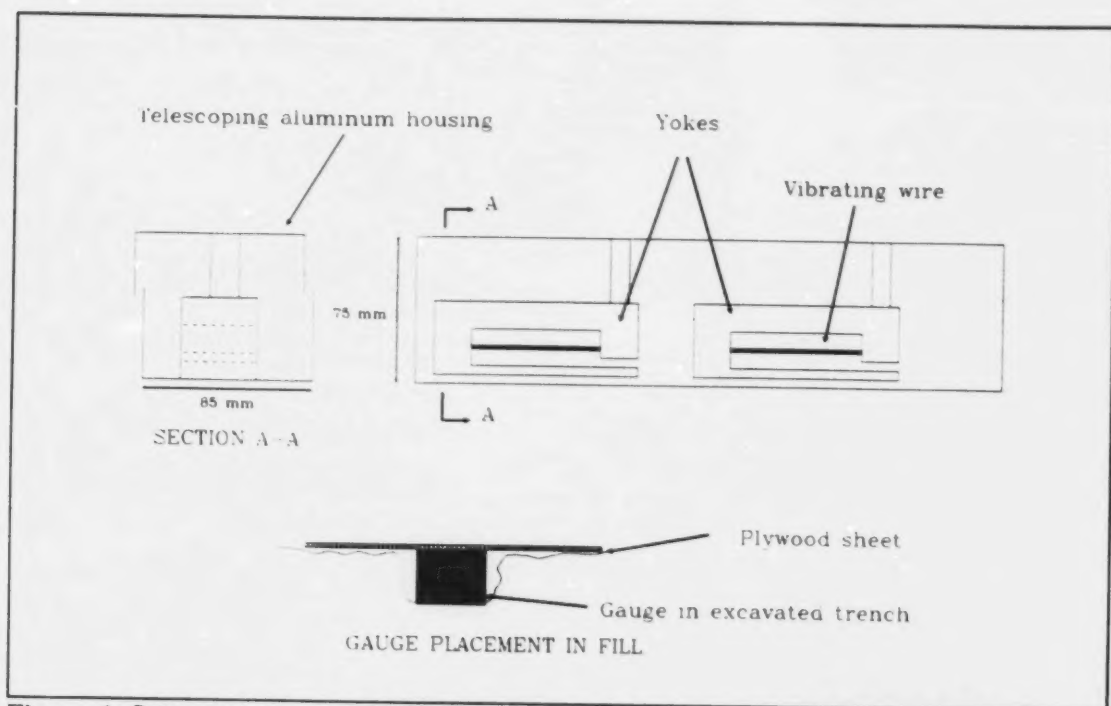


Figure 4 Schematic sections of CANMET vibrating wire consolidation gauge.

flexibility the ramp system offered for testing the RF transmission system. The stope has a sill elevation of approximately -522 m (545 m below surface) and it had been mined to an elevation of -490 m at the time instruments were installed. The tailings surface was at elevation -496 m, so a total of 26 m of tailings had been placed. The stope has an average dip of 75°.

In addition to the prototype instruments which were made during this project, other 'off-the-shelf' instruments were also installed at this site. The intent was to provide as detailed a picture of tailings behaviour as possible in order to correctly interpret the data from individual instruments. The complete installation is detailed in Table II and shown schematically in Figure 6.

Table II Instrumentation installed in 1500-2 stope at elevation -490 m

Instrument Description	Location
Roctest WR-FLEX 5 point extensometer with anchors at 3, 6, 9, 12 and 15 m	+40° in hanging wall
WR-FLEX extensometer as above	-8° in foot wall
Geokon 4800E earth pressure cell 1000 psi max	against and parallel to hanging wall
Geokon 4800E earth pressure cell 500 psi max	against and parallel to footwall
3 Geokon 4800E earth pressure cells 500 psi max	horizontal and 2 perpendicular vertical axes in the middle of the stope
Roctest COR-P telescopic closure meter 8.2 m long	horizontally, perpendicular to stope walls, with ends approximately 1.5 m from walls
CANMET consolidation meter, 467 mm long	vertical 1.2 m from hanging wall
CANMET consolidation meter, 467 mm long	vertical, centre of stope
CANMET tiltmeter	45° to horizontal, parallel to hanging wall, 1.2 m from wall
CANMET tiltmeter	45° to horizontal, along strike of stope, centre of stope
CANMET vibrating wire consolidation gauge	horizontally 1 m from footwall

5. Results

All instruments were installed in March, 1990; this was much later than had been anticipated at the beginning of the project. Delays were caused by a combination of

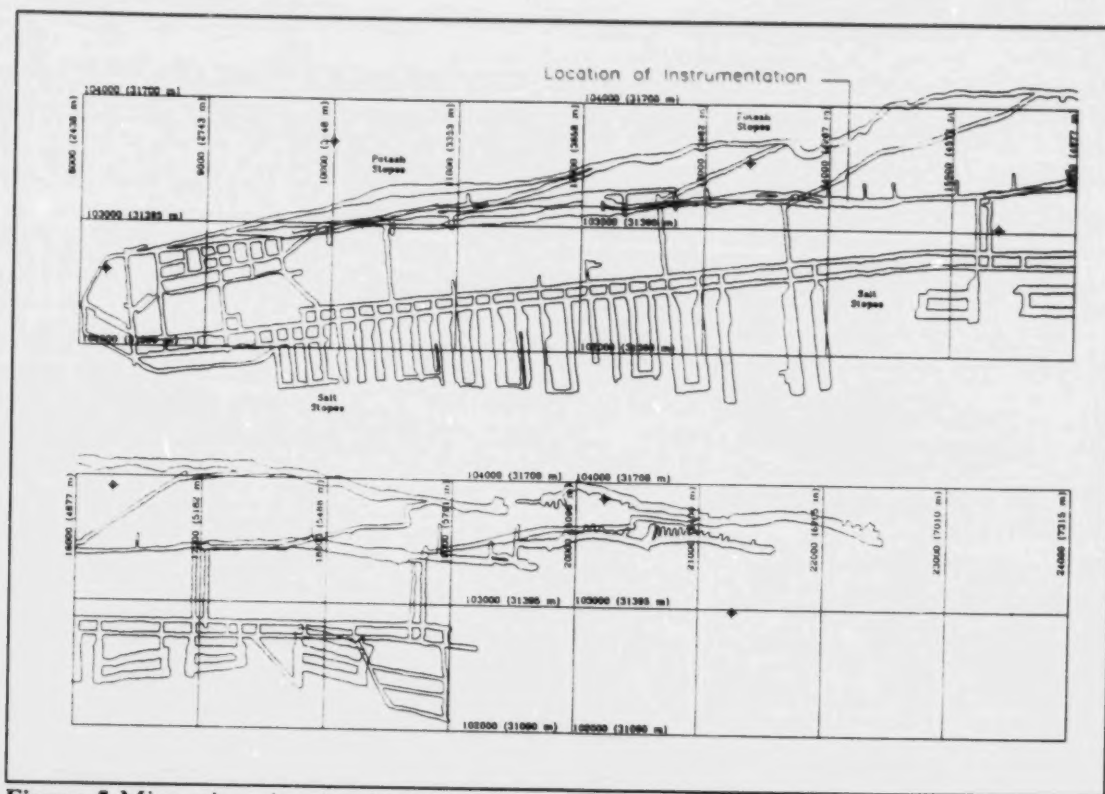


Figure 5 Mine plan showing location of instrumented stope

supplier delays and fabrication difficulties. At the time of completing this report, the instruments have all been covered with one 4 m lift of backfill and a second lift has been partially placed. The mining machine has cut one 4 m lift from the stope back and has traversed over the instruments twice. Earth pressure cells were installed one lift below the other instruments and therefore have an additional 4 m of fill above them. In the following sections, the results from each instrument are described. Figures 7 to 14 are plotted with the x axis having "DAY 0" at February 1, 1990 which was the date of installation of the earth pressure cells. The remaining instruments were placed during the period March 21 to March 30, 1990.

5.1 Earth Pressure Cells

Earth pressure cells were placed against each wall, parallel to the wall, and in the centre of the stope, one horizontally (CH), one parallel to strike (CV) and one perpendicular to strike (CTV). All were packed in silica sand before being covered in compacted tailings.

Erratic behaviour of the pressure cells began soon after they were installed (Figure 7). This may be due in part to damage caused by the mining machine as it first cut over them. The hanging wall and footwall cells may also have lost pressure because of a loss of the sand packing as the tailings shrank away from the wall. If that is the case, they

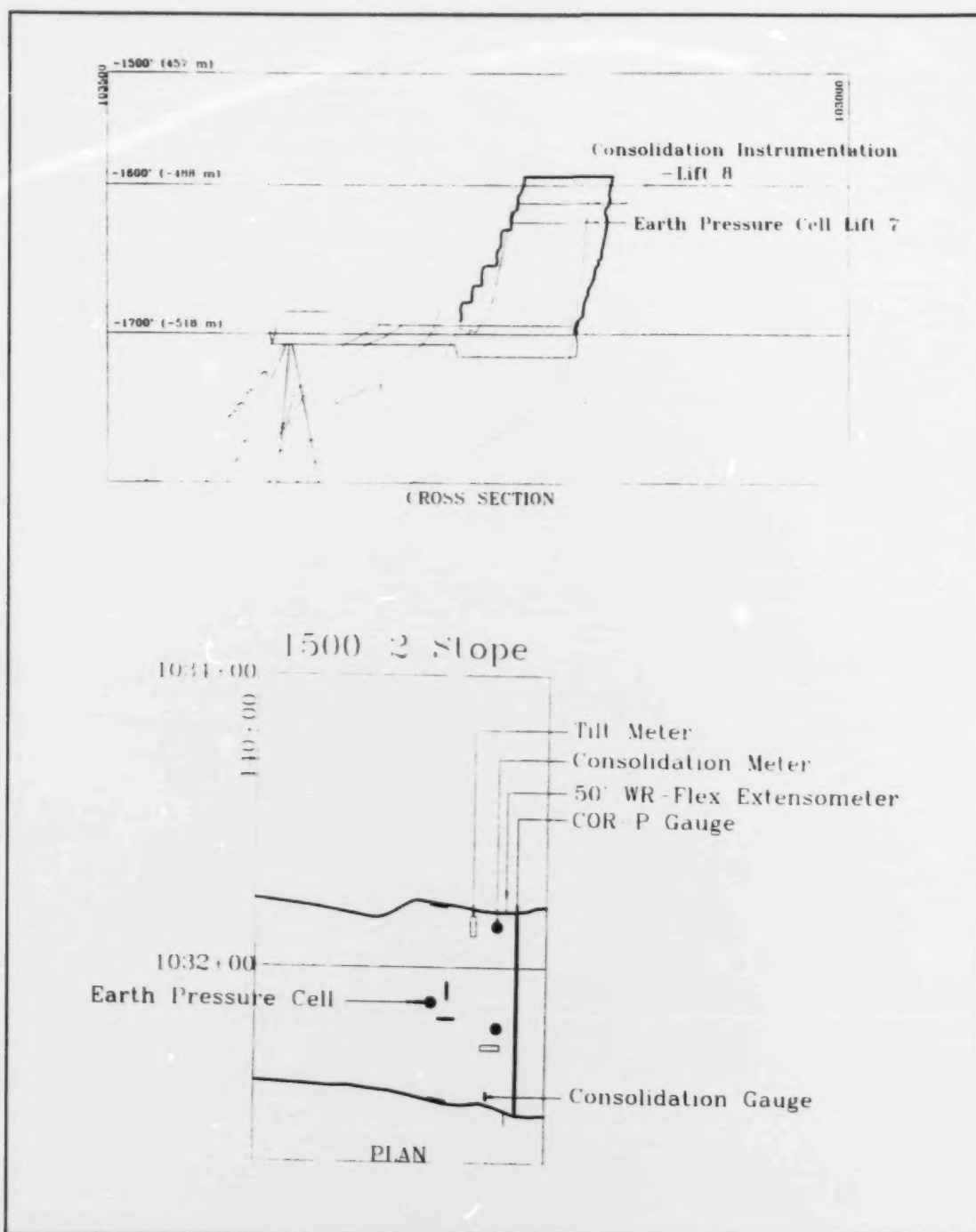


Figure 6 Schematic of instrument locations in 1500-2 stope

should regain pressure as the tailings consolidate and the walls encroach upon them. Only the CV cell is yielding the anticipated results, giving a consistent rise in pressure, although all the cells responded simultaneously to the addition of the second lift of fill around day

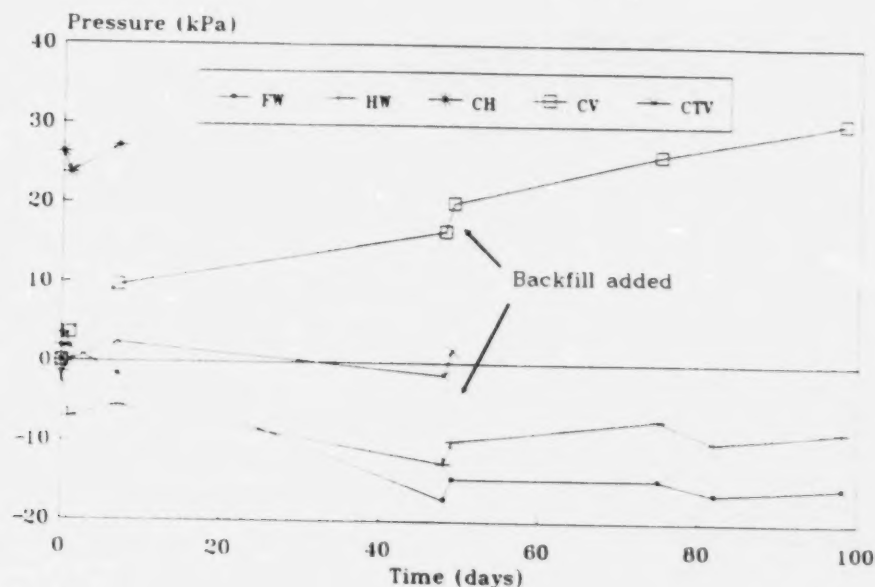


Figure 7 Earth pressure cell results

50. A single lift of fill should result in a rise in the vertical pressure (cell CH) of 50 to 60 kPa. Other sites have shown that subsequent lifts have a rapidly decreasing influence.

5.2 Extensometers.

The extensometer in the hanging wall registers a maximum expansion of 6 mm over 12 m. The 15 m anchor appears to be slipping, causing a lower reading than on the 12 m anchor. The total closure rate in the stope is about .75 mm per day indicating the a hanging wall expansion of 12 to 15 mm over the monitoring period could be expected. Deformations are obviously occurring beyond the extensometer depth and a longer extensometer will be placed in the area once drilling equipment is available. The original plan called for a 30 m extensometer, but this was replaced by the 15 m unit because of drilling problems.

5.3 Consolidation gauge.

The vibrating wire consolidation gauge provided a sensitive measure of consolidation and recorded each of the salient events in the mining cycle. It was buried 1 m from the footwall in which location it will not have experienced the full load of the mining machine or the maximum degree of compactive effort during backfilling.

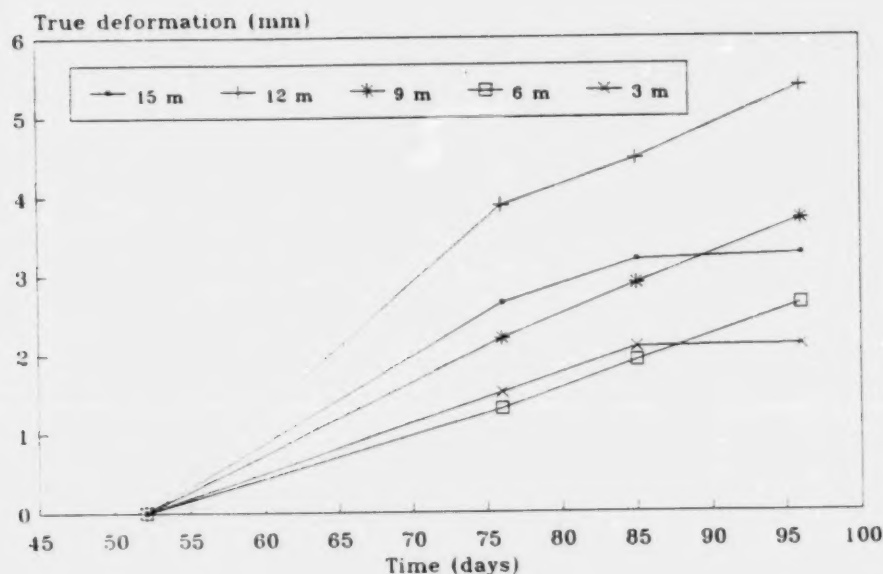


Figure 8 Hanging wall expansions derived from multi-point extensometer results

Figure 9 contains the consolidation data from each yoke of the gauge. The difference between the two yokes indicates that the load was applied eccentrically, probably because the end of the gauge closest to the wall received less compaction from the scoop trams which spread tailings. Placing of the first lift of backfill was a discontinuous operation because delays were forced by the need to grout and cable the extensometers. Continuing creep consolidation then took place with slight discontinuities as the mining machine cut above the gauge and then trammed back to the other end of the stope. Placement of a new lift of fill had just begun at the end of the logging period.

Mean unit weight of the fill following initial compaction is 14.9 kN/m^3 . There is a tendency for the unit weight to decrease from the footwall to hanging wall although this is not very marked in a steeply dipping stope such as the 1500-2 stope. Average densities may, in fact, approach 15.1 kN/m^3 at the instrumented location. In that case, consolidation to date would have increased the unit weight to 15.4 kN/m^3 . Steady state creep consolidation was occurring at a rate of .018% per day under 1 lift of fill.

5.4 Consolidation meter

Consolidation meters of approximately 600 mm length were installed in the centre of the stope and 1.2 m from the hanging wall. The instruments were measured manually with an ohm-meter. 100 mm travel on the meter results in a change in the potentiometer resistance from 0 to 20,000 Ω

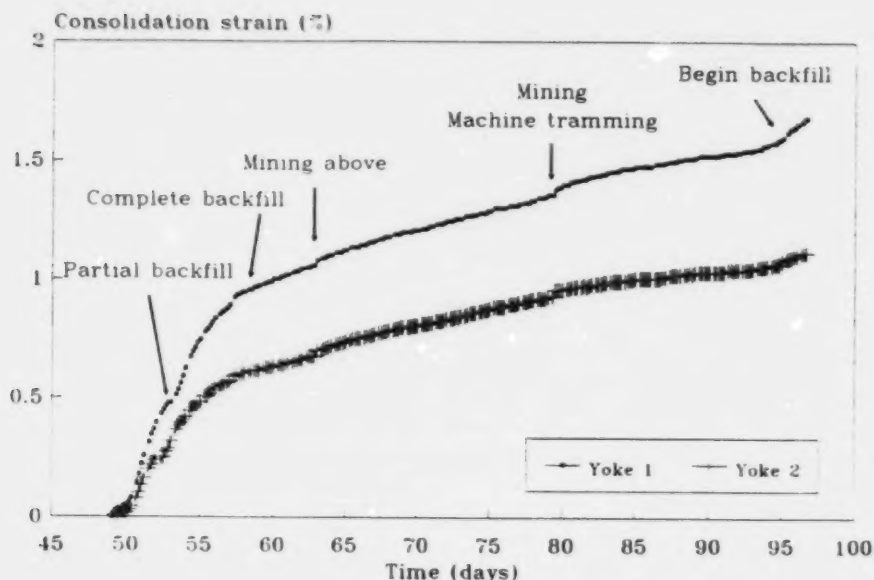


Figure 9 Consolidation strains in backfill at the footwall measured by CANMET consolidation gauge

Monitoring was continued through the placement of one lift of fill up to the start of the next lift. A total consolidation of 2.05% was measured in the centre of the stope, which is in reasonable agreement with the results from the vibrating wire consolidation gauge. On the hanging wall, where less compaction is achieved, the total consolidation is only 0.7%. The reason for lower consolidation is believed to be a combination of a wall effect and the fact that the mining machine could not have operated directly above the meter because of the angle of the wall.

The steady state creep consolidation rate was 0.017% per day at the centre of the stope and 0.0057% per day at the hanging wall.

The COR-P gauge which was buried across the width of the stope functions in a very similar way to the consolidation meter. Its length between bearing plates was 8.2 metres. Each end was approximately 1.2 m from the wall. The aim of the installation was to measure total horizontal strain of the fill rather than stope closure. Over the monitoring period, the instrument registered no movement, indicating that all closure of the stope was absorbed by the 1.2 m layer of fill adjacent to the walls. This information has implications for the design of backfill systems which aim to maximize hanging wall support while providing some flexibility in average density for mass balance purposes.

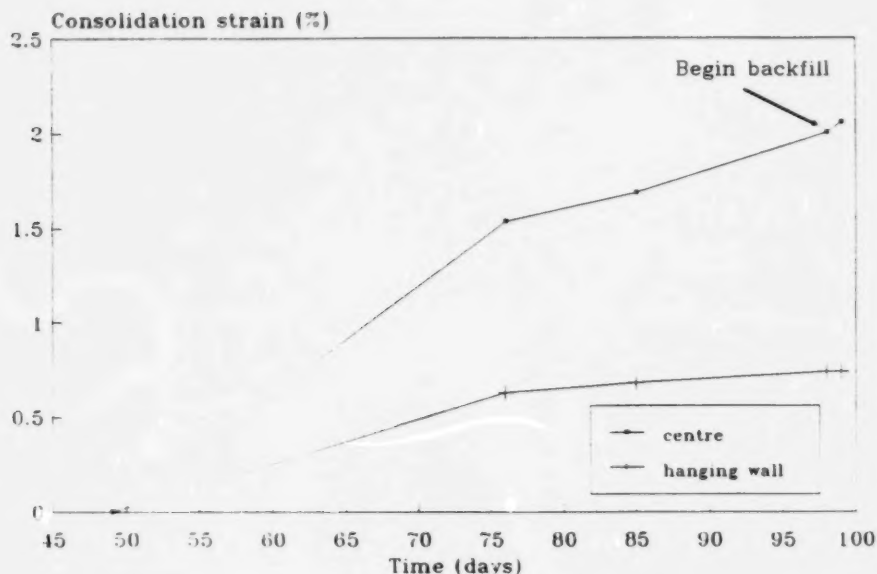


Figure 10 Consolidation strains in backfill measured with consolidation meter.

5.5 Tiltmeters

Two types of information are available from the tiltmeter data; the X axis tilt provides the rotation of the long axis of the meter and thus yields the vertical consolidation and the Y axis tilt indicates rotation of the meter about its long axis and thus the rotation of the fill as it consolidates. Rotation results from movement of fill into low density areas against the wall and from shear failure under high imposed loads which might be caused by the mining machine or by high overburden loads. The tiltmeters were not connected to a power supply until March 30, 1990 which was after completion of the only lift of tailings which has been placed on the instrument location to date. Power then failed on April 2 and was not restored until April 14, 1990.

Both X and Y axis tilts suggest a gradual creep consolidation of the fill between backfilling events. The beginning of the data record (Figure 11) is erratic as a result of the last movements of the backfill equipment. Meter 542, which is placed in the centre of the stope, undergoes the greatest X axis tilt, but as expected, there is very little rotation in the Y axis. The meter on the hanging wall indicates less consolidation but a greater Y axis tilt; this is presumably caused by fill spreading into shrinkage voids along the wall. Meters 542 and 544 are placed in opposing directions, thus the Y axis rotations are in fact both indicating a clockwise rotation of the fill around the east-trending strike of the stope.

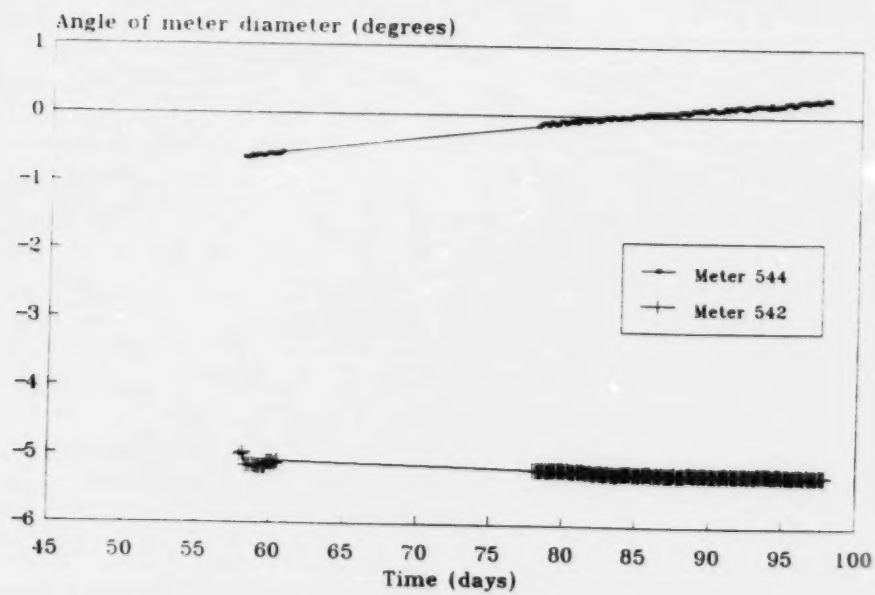
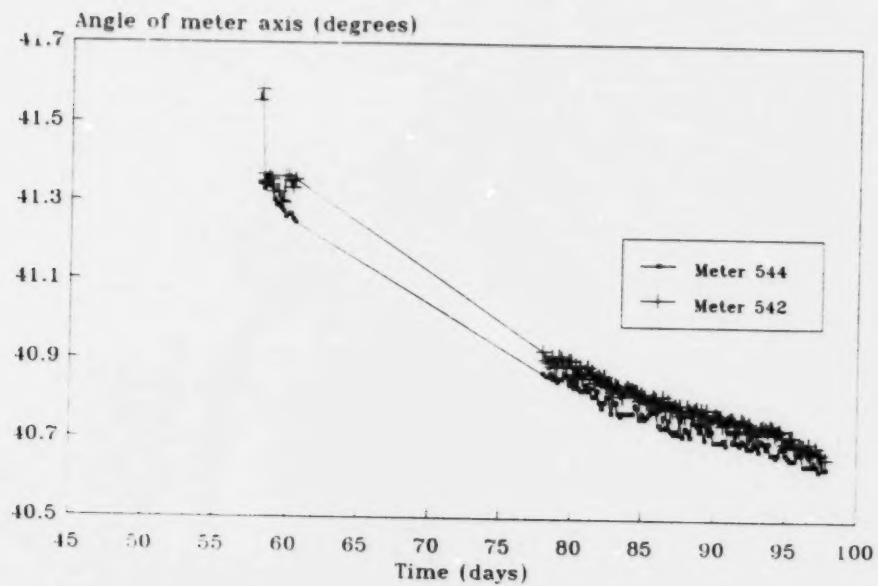


Figure 11 Rotations of tiltmeters 542 (centre slope) and 544 (hanging wall)

Figure 12 provides the consolidation strains derived from the X axis rotations. A steady state creep consolidation rate of 0.18% per day is indicated by both meters. The centre stope locations in good agreement with other instruments while the hanging wall meter gives a value considerably higher than the consolidation meter which was placed only

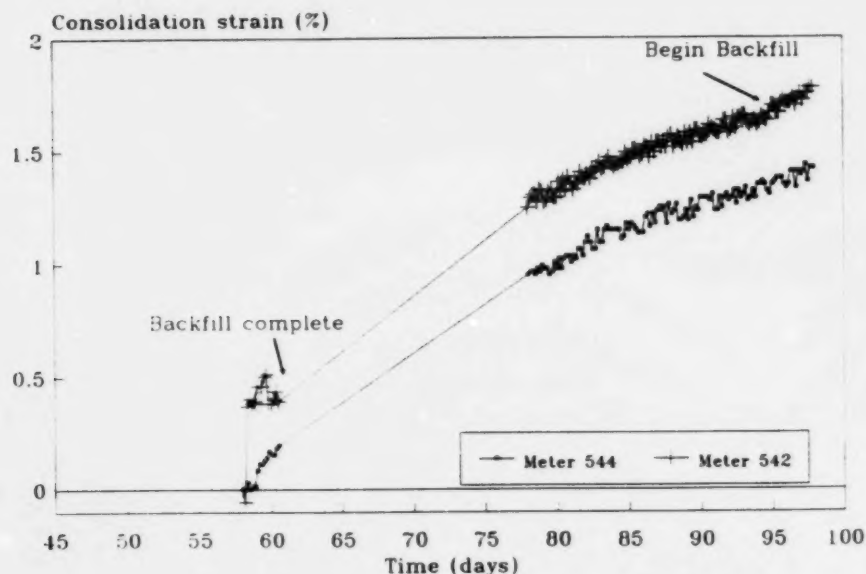


Figure 12 Consolidation of backfill derived form tiltmeter readings

about 0.6 m away. There is no clear explanation for this difference.

6 Conclusions

Several useful instruments for the measurement of consolidations in mine backfill have been developed and are being tested. The combined use of tiltmeters and either consolidation gauges or consolidation meters provides a complete picture of the deformations which are occurring within the backfill. The data collected by these instruments has application both in stope support design and in planning of the materials balance, which is of critical importance in a closed mining system.

A radio frequency data acquisition system has been developed for transmitting data through salt backfill. Production of a prototype has almost been completed and it will undergo testing in a potash stope during the second and third quarter of 1990. If the trials are successful, this system will greatly enhance the ease of collecting pressure and consolidation data in active mining areas where permanently installed, hard-wired systems are extremely prone to damage.

APPENDIX A

HOLOHIL SYSTEMS LTD. REPORT



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Attn.: R. Baddoes, Rock Research Consultant.

SUBJECT: RF Propagation tests through rock tailings.

On May 17/89 radio frequency propagation tests were conducted at the Potash Company of America facility in Sussex, New Brunswick. The purpose of the tests was to determine the RF absorption characteristics of the tailings at various radio frequencies.

Several tests were conducted in the tailing shed. At the time the shed contained well drained material at one end (3-4% water content) and freshly milled material at the other end (7-8% water content). The signal sources were two miniature fixed frequency transmitters with a power output of 10mw at 172.5MHz and 40.72MHz and a Marconi Model 2018 signal generator. The receivers were a Telonics Model TR-2 and a Hewlett-Packard Model 8554L/8552B spectrum analyzer.

In the first trial the 172MHz transmitter was buried in the well-drained tailings to varying depths and was monitored with the Telonics receiver. The transmitter was placed in a cavity dug into the tailings pile near the floor of the shed and the signal was monitored from the top of the pile (approx. 10m above the cavity). Good reception was obtained with up to 1 meter of fill covering the transmitter and antenna. Between 1 meter and 2 meter of fill the signal strength dropped considerably. At 2 meters of fill the signal was detectable but unusable.

In the second trial both transmitters were covered with fresh tailings to varying depths and a metal conductor was buried next to the transmitter antennas and extending a meter beyond the backfill. The signals were measured with the H-P analyzer and the 172MHz signal was also monitored with the Telonics receiver. Measurements were made with the no cover, with 1 meter of cover and a conductor, and with 1 meter of cover and no conductor.

The table below lists the signal strengths measured.

<u>Frequency</u>	<u>No Cover</u>	<u>1m Fill & Cond.</u>	<u>1m Fill no Cond.</u>
40.72MHz	-70dbm	-95dbm	-105dbm
172.50MHz	-56dbm	-95dbm	Not detected

Although the 172MHz signal was not detected by the spectrum analyzer when the conductor was removed, the receiver was able to pick up a signal. The noise floor (minimum detectable signal) of the spectrum analyzer is approximately -110dbm and the noise floor of the receiver is approximately -140dbm.

In the third trial the source of RF was the signal generator connected to an antenna via a 7m coax cable. The antenna and approximately 2m of coax cable were covered with 60cm of freshly-milled tailings. The radiated signal was measured with the H-P spectrum analyzer.

The table below lists the signal strengths measured.

<u>Frequency</u>	<u>No Cover</u>	<u>60cm Cover</u>	<u>Signal Loss</u>
30MHz	-38dbm	-55dbm	17db
220MHz	-45dbm	-62dbm	17db
400MHz	-56dbm	-80dbm	24db

A number of tests have subsequently been conducted at Holohil Systems Ltd. in sand and soil to attempt to explain the results obtained at Sussex. Unfortunately the high ionic content of the tailings could not be duplicated. This ionic content is the probable reason for the discrepancies between the observed and expected results. The higher moisture content and consequently the ionic content of the tailings in trials one and two explain the different absorption results.

The results of trial one indicate that transmission at 172MHz through low moisture content tailings is possible with or without a conductor near the antenna.

Trial two showed that a conductor buried beside the antenna will carry the signal through a high ionic medium and reradiate that signal above the backfill. The lower frequency signal in this trial seemed to perform better even if the conductor was removed. The small difference in signal strength cannot be explained. A test performed in a salt solution (2% NaCl) produced vastly different figures. Both signals disappeared as soon as the antennas were below the surface of the solution.

Trial three seemed to confirm that a significant amount of the RF energy is conducted along the surface of the wire emerging from the backfill and this seems to be independent of the material covering it or the frequency of operation.

While the tests did not conclusively show one frequency to be superior to another, it was demonstrated that either frequency is usable. A conductor buried along with the transmitting antenna and emerging from the backfill greatly improves transmission capabilities at either frequencies. The moisture and ionic content of the backfill has a definite influence on transmission capabilities of either frequency.

For the next development phase I propose to construct single channel prototype transmitters at both frequencies and evaluate their respective performances in situ. If necessary, the power output of the transmitter could be raised for better signal quality at the receiver. The higher output power requirements of the transmitter would not significantly affect the life of the system due to the low transmission duty cycle, ie. one 3 second transmission every 4 hours.

To further increase the range of the system to the next gallery or to another level, a variety of active and passive wireless repeater systems can be employed. The type used would depend on the specific situation encountered.

If you require any further information or clarification, please call me at any time.

Fred W. Anderka



END

APPENDIX B

CANMET REPORT ON TILTMETER DESIGN AND OPERATION

**A TILT METER SYSTEM TO MEASURE CONSOLIDATION IN
WASTE SALT BACKFILL**

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A TILT METER SYSTEM TO MEASURE CONSOLIDATION IN
WASTE SALT BACKFILL

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SUMMARY

Tilt meters possess the potential for high resolution tilt/deformation measurements in very demanding environments. This report describes a commercial tilt meter system which has been modified to measure compaction in salt backfill. Other intended uses are the measurement of rotation of hanging wall and footwall strata during subsidence.

The resolution of the system with the base length of the mounting tube of 47.6 cm is 0.6 mm for the high gain setting with tilt angles limited to ± 10 degrees. Tilt sensor outputs are read and stored on the 21X micrologger datalogging system.

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Keywords: Monitoring, backfill, consolidation, waste, tiltmeter,

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1. INTRODUCTION

Waste salt placed into mined out openings at potash mines consolidates with time due to drainage and evaporation of water and due to recrystallization. Depending on original water content, grainsize distribution, and placement, the consolidation rate will vary. For the determination of support, waste salt will provide to the walls, floor, and roof of mined out openings, the consolidation rate needs to be known.

The New Brunswick/Canada Mineral Development Agreement provided the opportunity for the Mining Research Laboratories, CANMET to develop instrumentation for this particular purpose in cooperation with the Potash Company of America, Sussex, N.B., a Division of Rio Algom Ltd.. A number of instrumentation systems were developed and installed by Potash Company of America in the Sussex potash ore body for field monitoring. One of them is a tiltmeter monitoring system which is described below.

Tilt meters are capable of high precision outputs and are used in many civil and mine engineering applications. They are generally of a rugged design and are offered by a number of manufacturers in a wide price range with varied capabilities. Waste salt backfill shows shrinkage in the order of centimetres to meters depending on the distance over which it is measured. Tilt meters offer the possibility of avoiding the problem of trade off of range against sensitivity because the primary measurement is angular measurement.

2. EQUIPMENT

After discussions with a number of suppliers and considering the time available for the project, it was decided to obtain a nearly complete system (tilt sensors, datalogging system) from Applied Geomechanics Inc., 1336 Brommer Street, Santa Cruz, CA 95062, California, US, through their agent, EMACO (Canada) Ltd., 2685 Paulus, Montreal, Quebec, H4S 1E9.

The following equipment was obtained:

Three model 1129-757 dual axis sensors in stainless steel holders each with 50m of cable;

Two model 785 signal conditioning field modules (SN 487, SN 1097);

One model 794 tilt meter power supply/junction box;

One 21X data logging system.

Three custom made water-proof stainless steel housings were obtained from Richard Brancker Research, Ottawa with an outside diameter of 6.0cm and a length of 47.6cm for mounting the tilt sensors inside. The equipment was delivered to the Instrumentation Section of the Canadian Mine Technology Laboratory, MRL, CANMET. The cost of the equipment was about \$15,000.

2.1 Tilt Sensor Details

The tilt sensors are to indicate the rotation of a 47.6cm long stainless steel pipe buried at 45 degrees to horizontal in salt waste during consolidation.

The 757 tilt sensors are wide-angle sensors with a resolution and repeatability of 5 microradian and a total range of ± 60 degrees. The stated linearity is within 0.1 degrees at ± 10 degrees and within 3 degrees at ± 60 degrees. For single-ended outputs two scale factors are available for the wide-angle sensor:

Low gain setting	high gain setting
100mV/arc minute	10mV/arc minute
2V/degree	1V/degree

For differential analog outputs the above values double. The tilt cells are potted in place and the sensors are calibrated before shipping. Also potted with each sensor is a National Semiconductor LM35 thermistor. The model 757 tilt sensor operates over the temperature range -20 to $+70$ degrees C, and will function in 0 to 100% relative humidity. However, they are non-submersible and require an environment where condensation is not present.

The installation of the tilt sensors requires, for maximum sensitivity, burial at a 45 degree angle. As the sensor range in the factory supplied stainless steel mount was ± 60 degrees from vertical, the sensors were mounted on a 45 degree pedestal. This way the tilt sensor body containing the two tilt meters (x, y) is vertical when the stainless steel pipe is buried at an angle of 45 degrees (Figure 1).

The electronic features for the standard 700 series tilt meters are given below followed by factory calibrations for tilt sensors 542, 543, and 544.

TILT OUTPUT	Two channels each of single-ended and differential analog outputs proportional to tilt angle
OUTPUT VOLTAGE RANGE	± 8 VDC (single-ended) and ± 15 VDC (differential)
OUTPUT NOISE	1 millivolt (single-ended), 2 millivolts differential
OUTPUT IMPEDANCE	270 ohms, reverse voltage and surge protected
GAIN RANGE	Two gains provided, high = 10:1 low = 2:1
OUTPUT FILTERS	Two low-pass integrators: Preset at 0.1 second and preset at 30 seconds
TEMPERATURE OUTPUT	Single-ended output, 10 mV/ $^{\circ}$ C, to 100° C at $\pm 0.75^{\circ}$ C accuracy
POWER REQUIREMENTS	+ 11 to 15 VDC, -11 to 15VDC, 14 mA typical, 250mV peak-to-peak

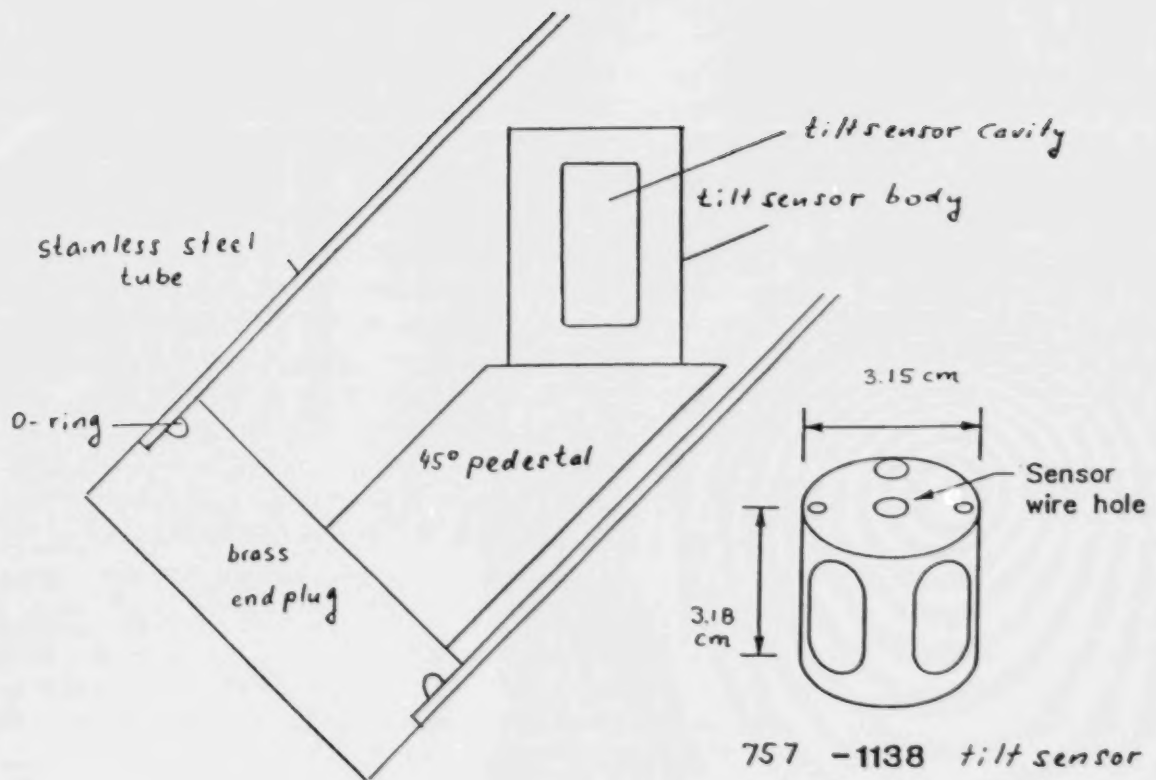


Fig. 1 - 45 degree pedestal for tilt sensor



EMACO (CANADA) LTD

2685 PAULUS, MONTREAL, QUEBEC, CANADA H4S 1E1
TEL: (514) 331-0551 FAX: (514) 331-5022

January 13, 1988

SPECIFICATIONS: 757-Series Wide-Angle Miniature Tilt Sensors

The 757 Series of Miniature Tilt Sensors includes five different sensor packages. Each package consists of a rugged dual-axis or single-axis solid-aluminum housing containing Applied Geomechanics' wide-angle (Type C) electrolytic transducers. The housings are in a variety of shapes and dimensions to accommodate a wide range of mounting and space requirements. Mounting holes allow for easy attachment to any vertical or horizontal surface. Signal conditioning for Miniature Tilt Sensors is provided by a Model 781 Signal Conditioning Unit, a Model 785 Signal Conditioning Field Module or a Model 775 Readout/Electronics Unit.

RESOLUTION	10 microradians (2 arc seconds)
TOTAL RANGE	± 60 degrees
REPEATABILITY	50 microradians (10 arc seconds)
LINEARITY	Within 0.1 degree at an angle of ± 10 degrees, within 1.0 degree at an angle of ± 45 degrees, within 3 degrees at ± 60 degrees
OUTPUT CONNECTIONS	12-inch (30 cm) pigtails with tinned ends or molex connectors
ENVIRONMENTAL RANGE	-20°C to $+70^{\circ}\text{C}$ operational, -30°C to $+100^{\circ}\text{C}$ storage, 0 to 100 % humidity
MATERIALS	Anodized 6061-T6 aluminum; stainless steel, invar, brass or ceramic available upon request
SIGNAL CONDITIONING	Provided by Applied Geomechanics Models 775, 781 or 785

MODEL	CHANNELS	MOUNTING	DIMENSIONS	WEIGHT
-1138	2 tilt, 1 temp.	Horiz. surface or vert. tube; mounting hole dia. = 0.14" (3.7 mm)	1.24" dia. cylinder x 1.25" high (31.5 x 31.8 mm)	2.5 oz. (71 g)

Signal Conditioning Unit serial number: 487Signal Conditioning Unit model number: 785

"SENSOR X" CHANNEL								
Transducer Serial No.	Calib. Temp.	Calib. Range, $\pm$	Scale Factors				Single- ended	Differ- ential
			High Gain	r^2	Low Gain	r^2		
542	20°C	See	937.62	.9999	130.71	.9999	✓	
543	20°C	Below	1010.28	.9999	142.13	.9999	✓	
544	20°C		902.15	.9999	129.01	.9999	✓	

"SENSOR Y" CHANNEL								
Transducer Serial No.	Calib. Temp.	Calib. Range, $\pm$	Scale Factors				Single- ended	Differ- ential
			High Gain	r^2	Low Gain	r^2		
542	20°C	See	1141.06	.9999	153.17	.9999	✓	
543	20°C	Below	1007.86	.9999	133.95	.9999	✓	
544	20°C		1131.13	.9999	157.05	.9999	✓	

The scale factor of the temperature output is: 10 mV/°C

Scale factor units are: Millivolts per microradian

Calibration Range: High gain = ± 1.5 degrees
 Low gain = ± 10 degrees

2.2 System Calibration

For calibration the 47.6cm stainless steel tube was mounted on a tilt table which could be tilted using a 20 threads/inch lead screw. The x-axis of the tilt sensor was co-planar with the axis of the stainless steel tube in a vertical plane. The y-axis was horizontal. Tilt was measured for the x-axis only, whereas tilt sensor y was used only as a control to avoid rotation around the y-axis. Tilt sensor 542 was calibrated connected to the SN 487 signal conditioning unit and its voltage read with a digital volt meter. Tilt sensor 544 was calibrated with the SN 1097 signal conditioning unit. The hardware connections and the laboratory set up for tilt sensor calibrations are shown in Figure 2. The results of the calibration are reproduced below as degrees axial tilt of stainless steel tube against data logger voltage (stored values).

As any rotation of the y-axis will render the x-axis calibration invalid, a calibration for the y-axis is given with an additional calibration of the x-axis as conditioner output voltage against datalogger voltage.

A regression of tiltmeter voltage against degrees of tilt provided the following (Figures 3 to 10):

<u>Tilt Sensor</u>	<u>Estimate</u>	<u>Regression Coefficient</u>	<u>Intercept</u>
0542 high gain	x (+/-0.3V)	-1.85(+/-0.01)	84.1(+/-0.5)
0542 low gain	x (+/-0.1V)	-0.268(+/-0.008)	12.14(+/-0.04)
0544 high gain	x (+/-0.2V)	-1.82(+/-0.01)	82.2(+/-0.4)
0544 low gain	x (+/-0.06V)	-0.260(+/-0.005)	11.68(+/-0.03)

In the high gain setting the range is +/- 10 degrees and in the low gain setting the range is +/- 60 degrees. Voltage output is about +/-16V in both cases. For the high gain setting the range was centered on 45 degrees. Extrapolation of the regression line to zero degrees ends up with an intercept of 82 to 84V (high gain).

If the voltage error is attributed to the regression coefficient only, then the high gain setting has errors of $0.3/1.85 = 0.16$ degrees and $0.2/1.82 = 0.11$ degrees. For the low gain setting the error appears to be $0.1/0.268 = .37$ and $0.06/0.26 = 0.23$ degrees. The non-linearity according to factory specifications for a range of +/-10 degrees is 0.1 degree and for a range of +/-45 degrees is 1.0 degree.

Proper orientation of sensor connectors, which are not polarized, is essential and care must be taken when connecting them so that the red markings go together. Reversing the polarity of the tilt cell connections will cause degradation of the cells and a reversal of the sign of the calibration factor. Reversing X for Y will result in a similar reversal in the axis being read. The temperature sensor is not interchangeable with the tilt cells as the female/male

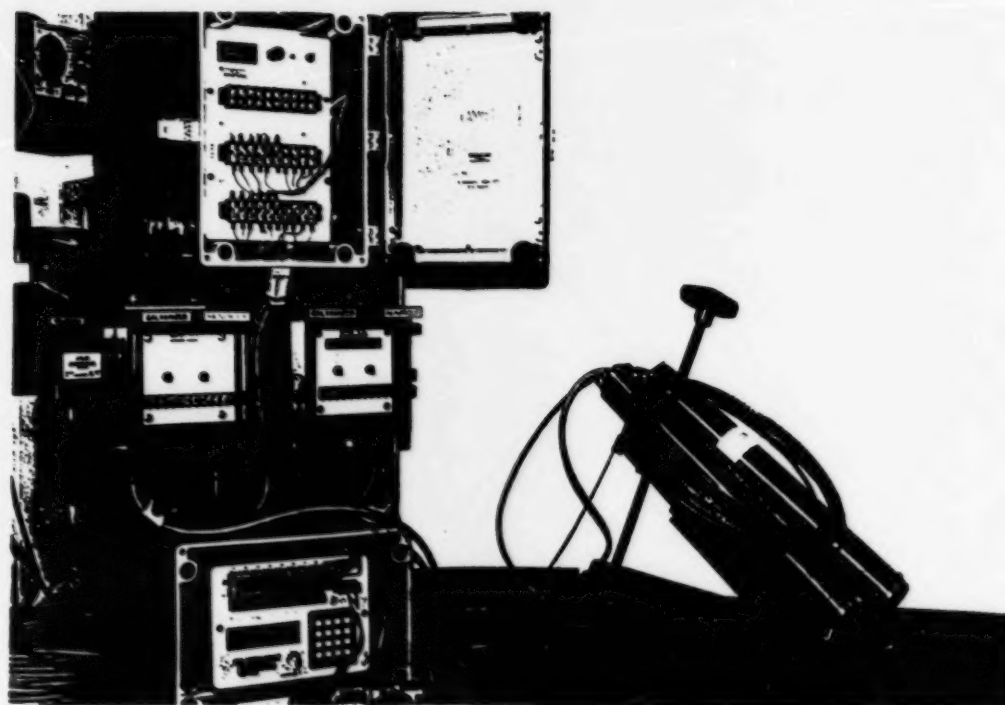
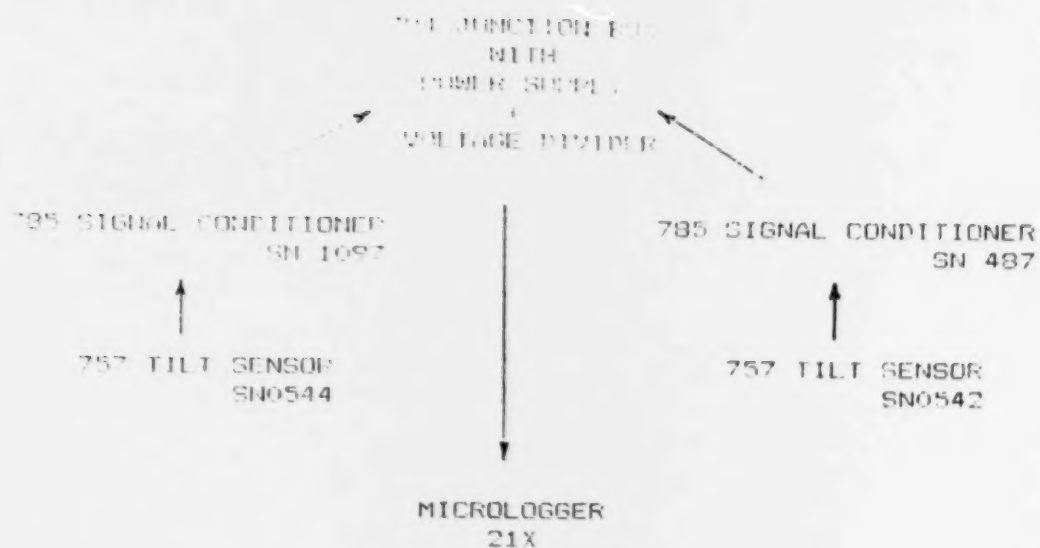


Fig. 2 - Hardware connections and laboratory set up for tilt sensor calibrations

connectors are reversed but must also be connected with the red markings together. Each tilt sensor was calibrated with its own individually labelled cable because the capacitance of the cable affects calibration.

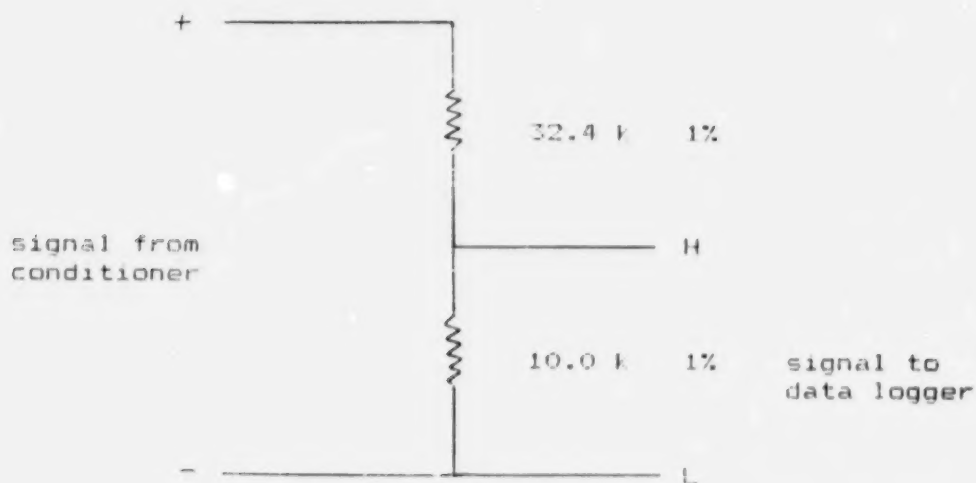
The end of the cable is connected to the conditioner unit with a multi-pin connector. This connector is polarized and can only be connected to the "Sensor Cable" connector. Connection to the "Power Cable" connector could damage the sensor. Each conditioner unit has a unique gain. Thus the units are labelled and must be used with the appropriate cable and sensor. The output voltage swing from the conditioner units is roughly ± 16 volts DC. The conditioners provide selection of "High" or "Low" gain and filtering "On" or "Off". "Low" gain gives a sensor conditioner an output of about 260 millivolts per degree and a "High" gain an output of about 2000 millivolts per degree. The filter when "On" has a settling time of 30 seconds, when "Off" 0.1 seconds. The thermistor output is 10 millivolts per degree Celcius.

The system has been prewired to the junction box and datalogger. The largest analog input range on the datalogger is ± 5000 millivolts. The conditioner output was attenuated by using voltage dividers. These dividers have been wired on terminal strips on the back side of the junction box panel. These dividers are only provided for the X and Y outputs from the conditioners and the external power supply, as the other signals will be within the input range of the datalogger. The actual signal attenuation of each divider was determined by applying a signal to the divider input and using the datalogger to read the corresponding channel. Results of this calibration are found in table 1.

Note: The datalogger works in millivolts not binary counts or volts and all calibration factors and offsets must be given in millivolts.

Originally only one conditioner (SN 487) was sent from the manufacturer, thus individual manufacturer's tilt meter calibrations were not available for the conditioner SN 1097.

Table 1 - Calibration of voltage divider



Divider	Input	Output	Attenuation
X1	15.00	3.5375	4.2292
Y1	15.00	3.5464	4.2452
X2	15.00	3.5468	4.2403
Y2	15.00	3.5334	4.2296
External Power supply	12.06	4.2645	4.2645

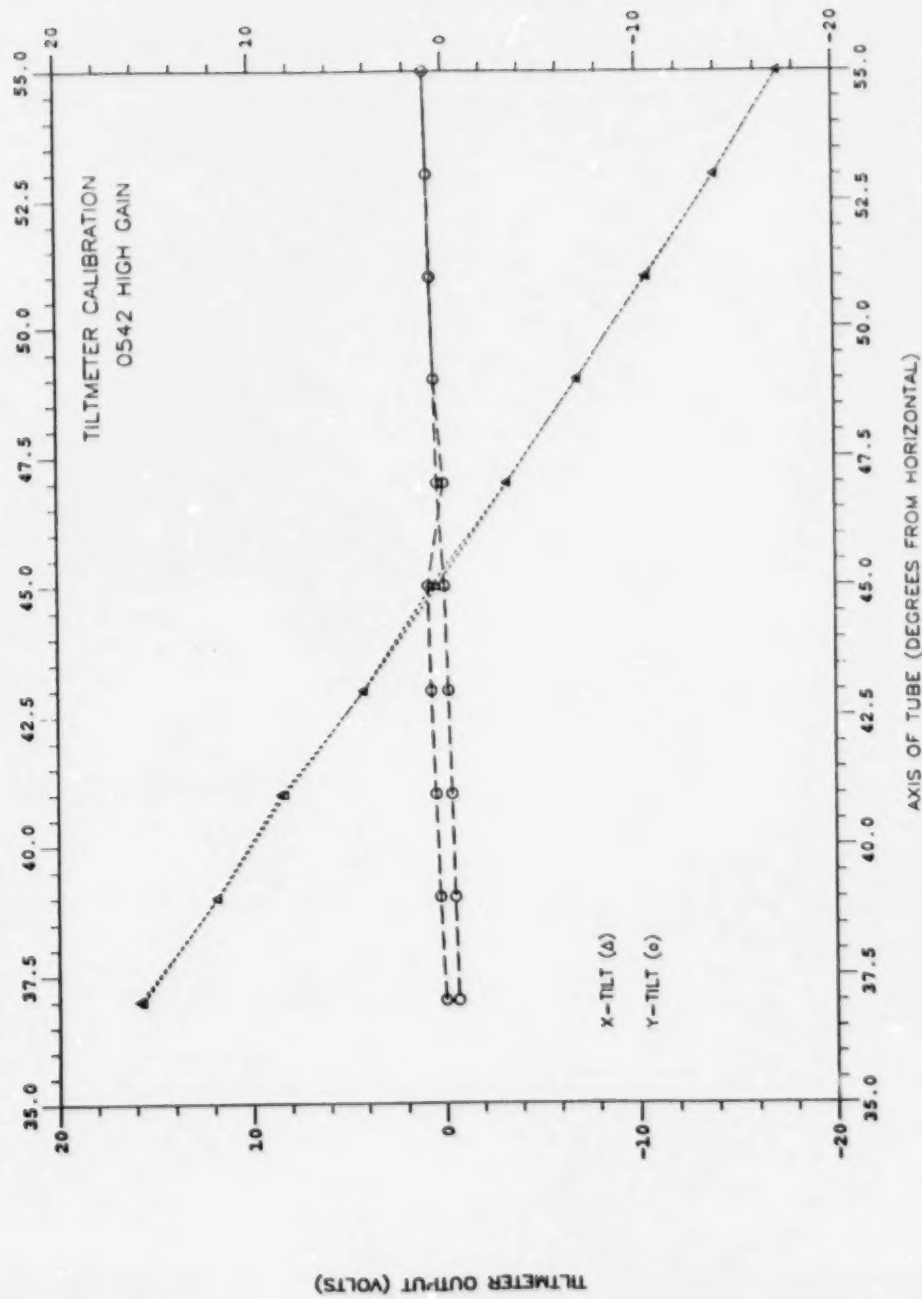
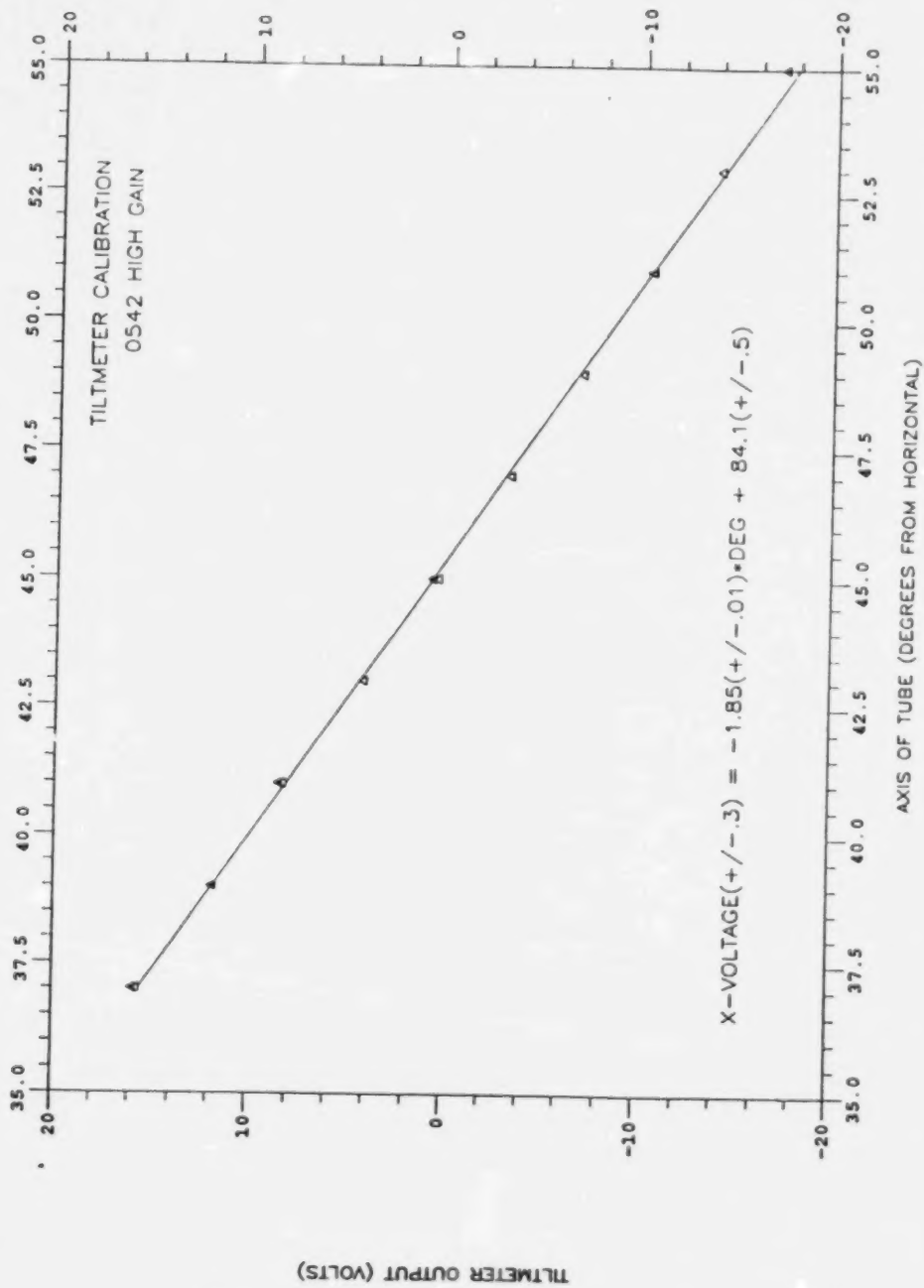


Fig. 3 - Tilt meter 0542 calibration (high gain)



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Fig. 4 - Regression of tilt meter 0542 calibration (high gain)

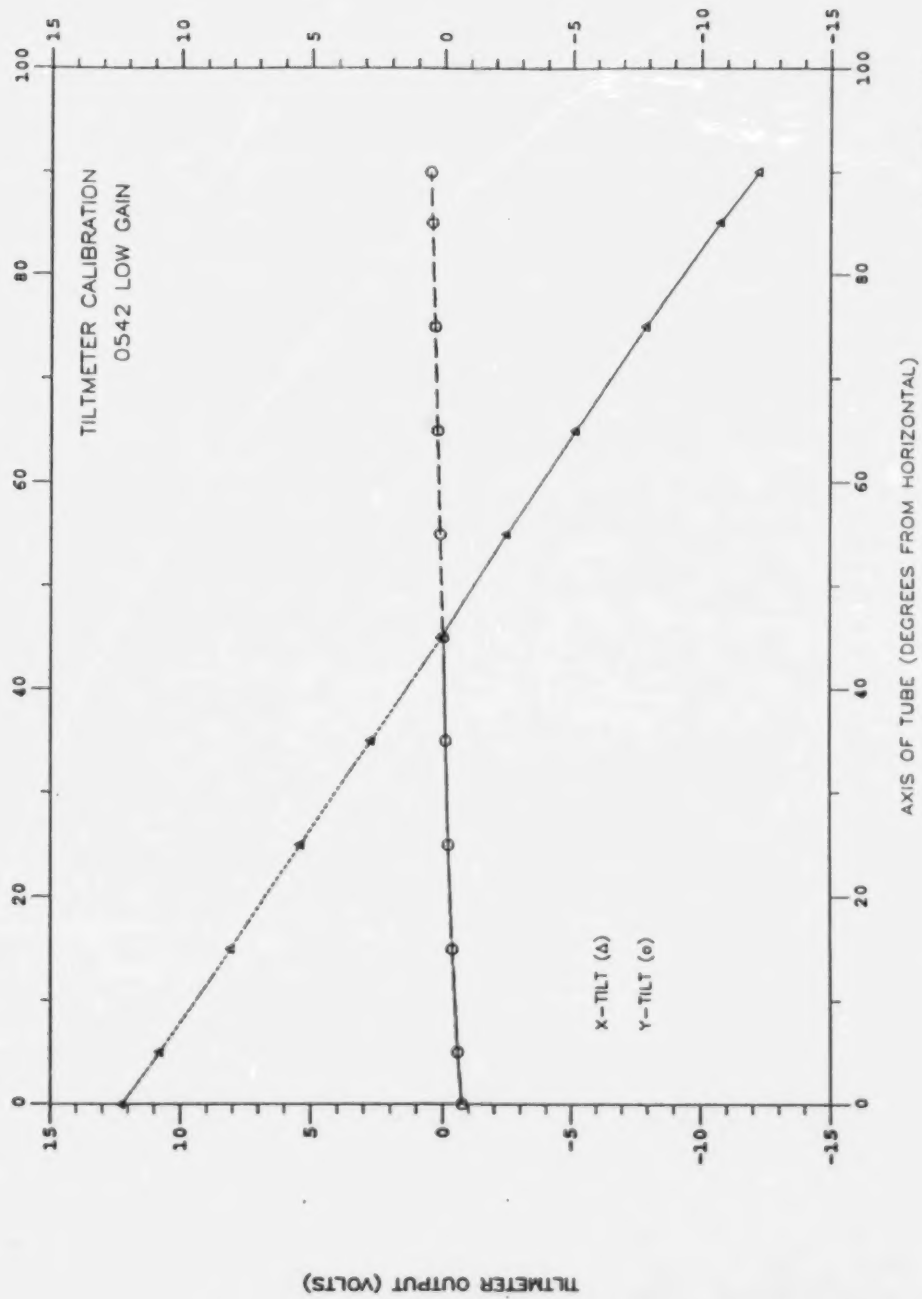


Fig. 5 - Tilt meter 0542 calibration (low gain)

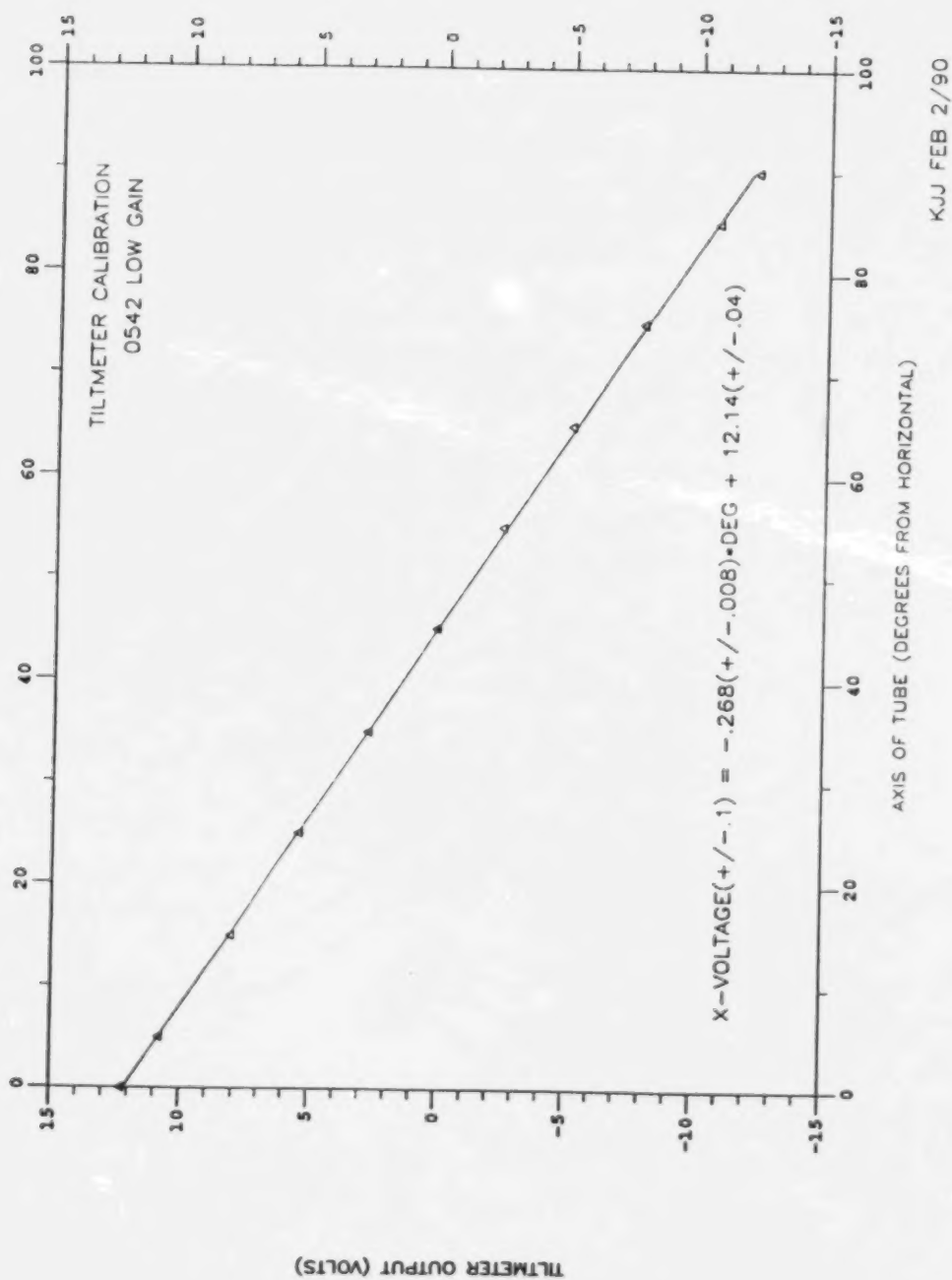
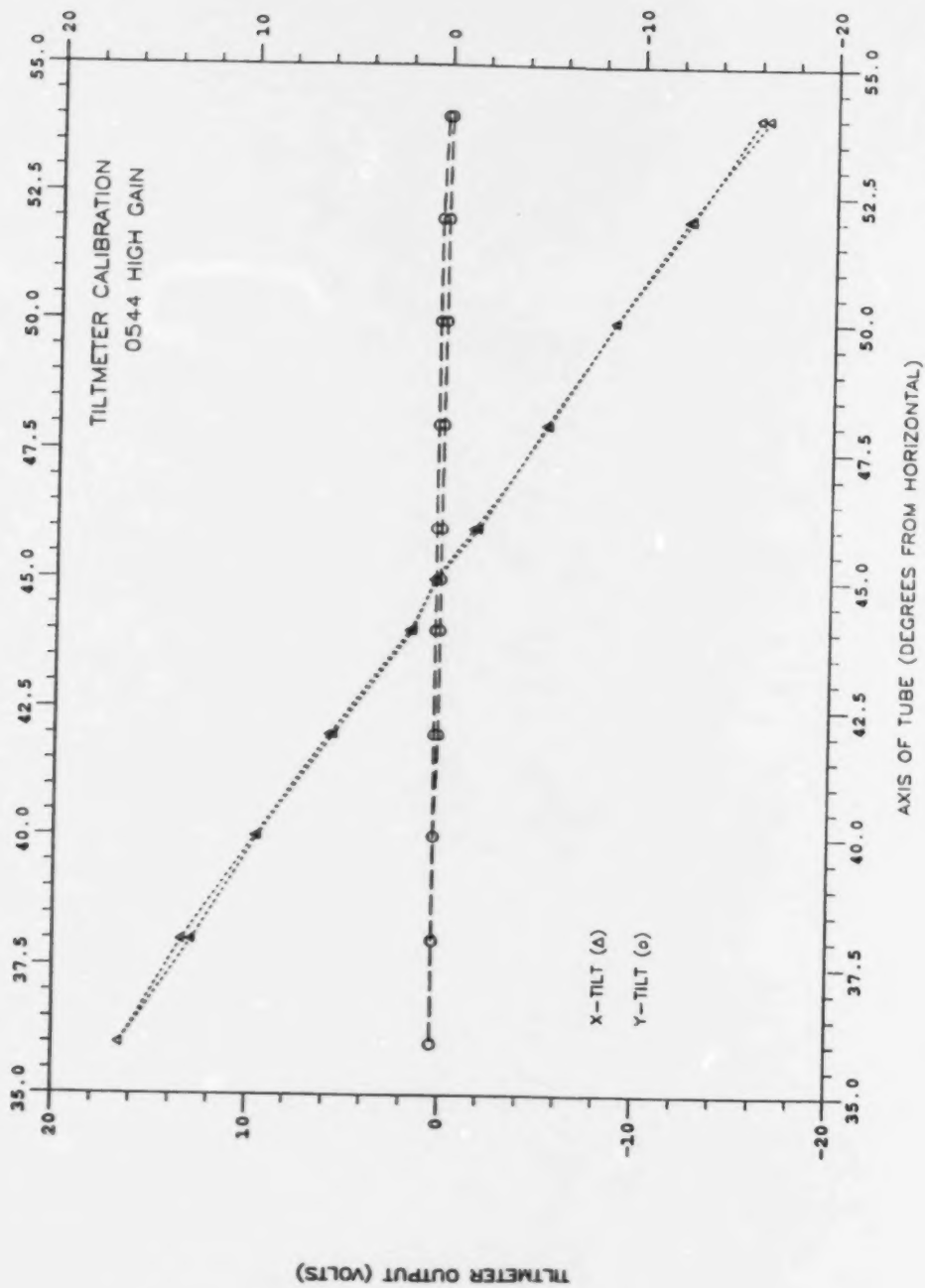


Fig. 6 - Regression of tilt meter 0542 calibration (low gain)



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Fig. 7 - Tilt meter 0544 calibration (high gain)

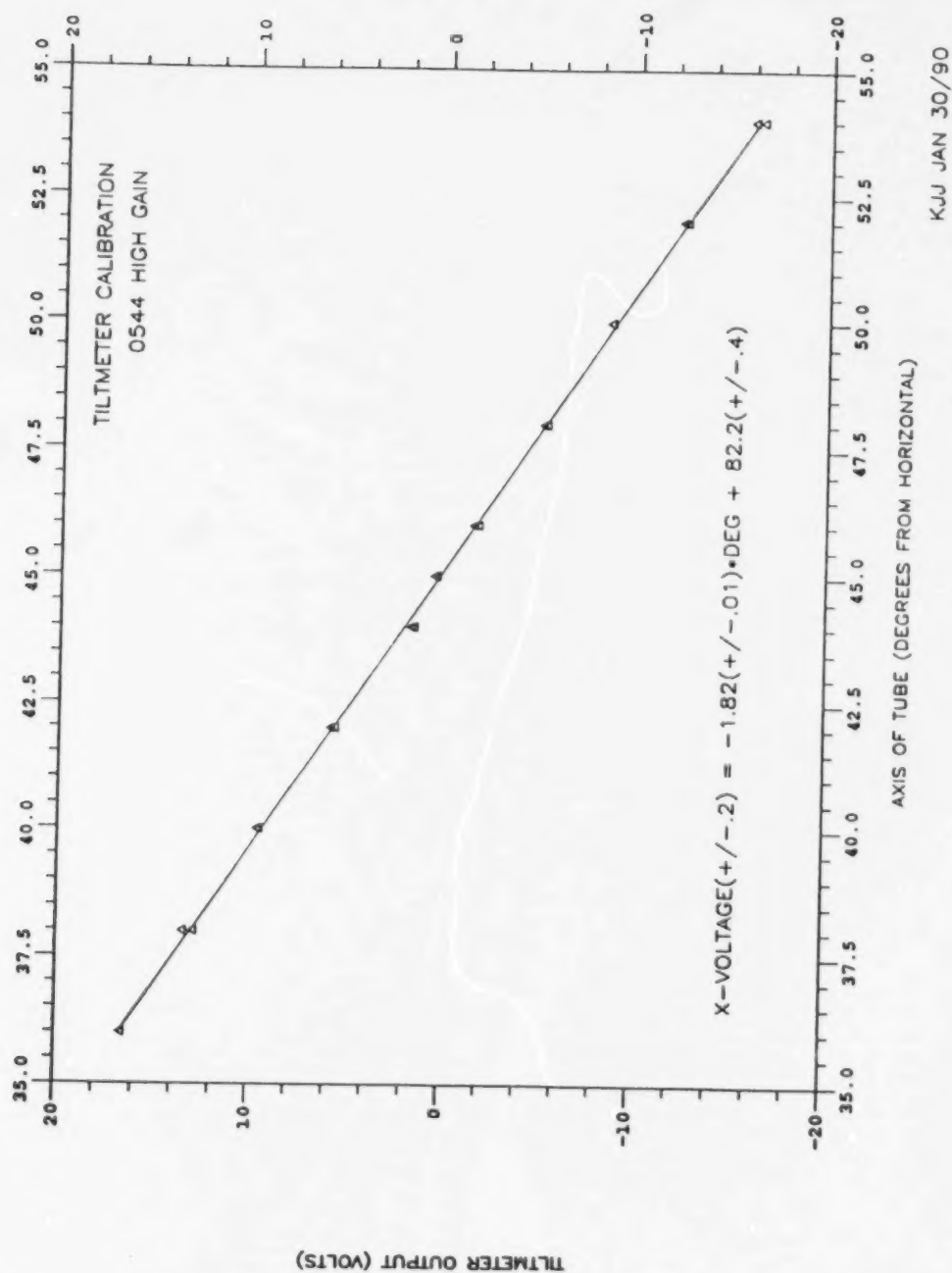


Fig. 8 - Regression of tilt meter 0544 calibration (high gain)

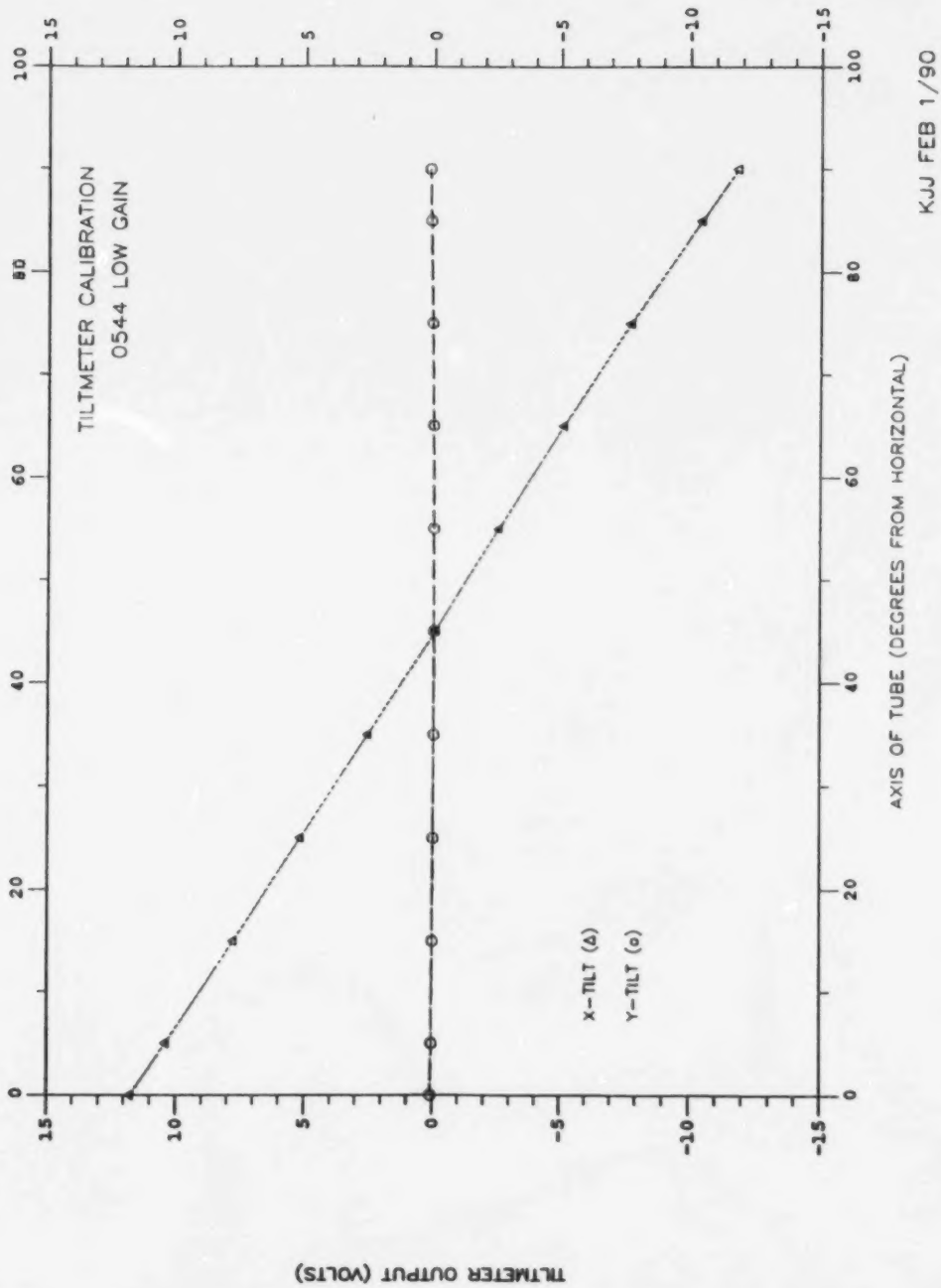


Fig. 9 - Tilt meter 0544 calibration (low gain)

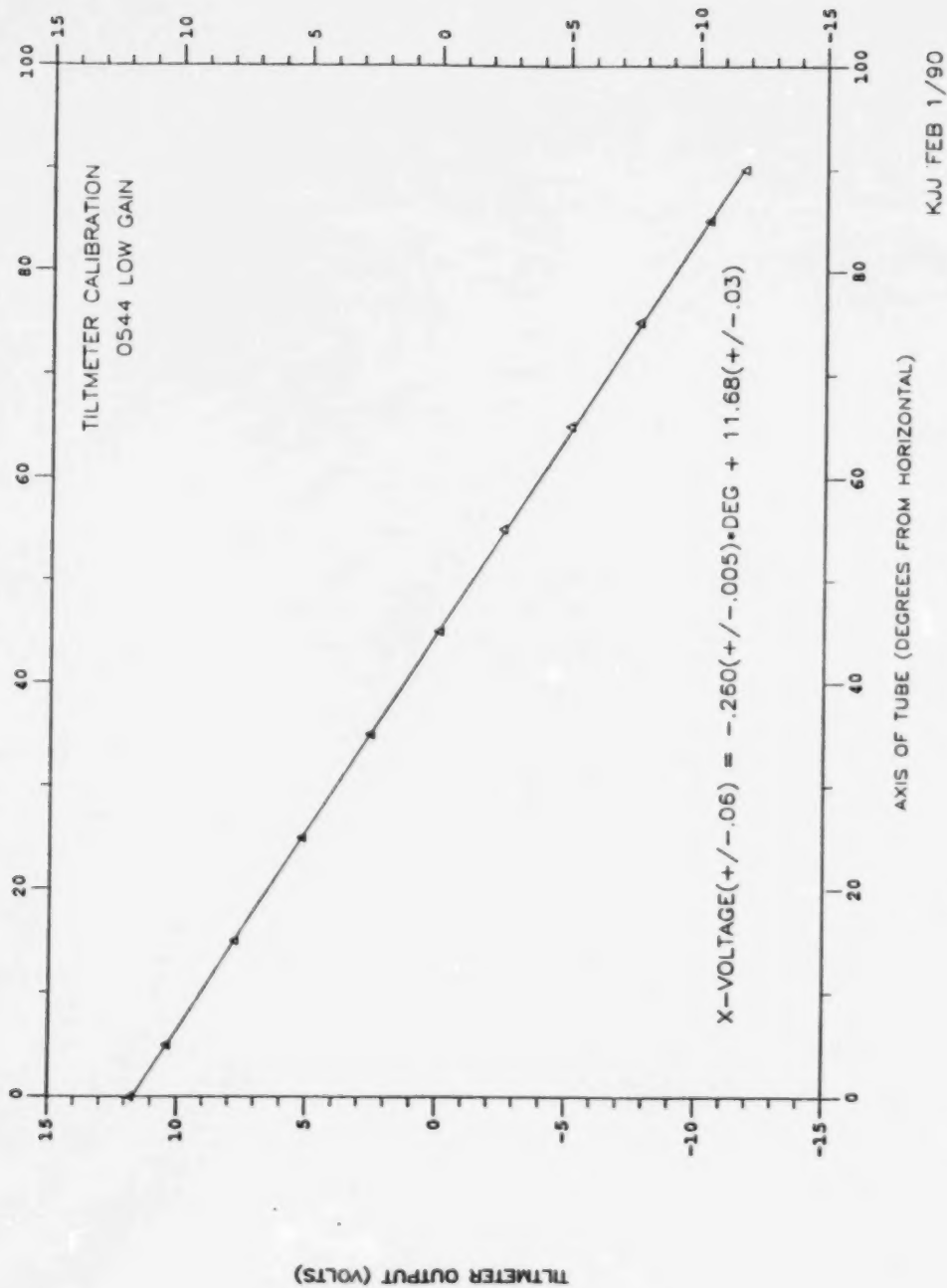


Fig. 10 - Regression of tilt meter 0544 calibration (low gain)

2.3 Consolidation Measurements with a Tilt Sensor

The length of the tilt meter housing is 47.6 cm(18.75 in.) and the following factory specifications were given:

High gain resolution = 1000 mV/microradian
 Low gain resolution = 150 mV/microradian
 System stability = 10 mV

Conversions:

1 degree = 0.017453293 radian
 1 radian = 57.296 degrees
 1 microradian = 0.0000573 degrees

High gain resolution: $0.0000573 \text{ degrees}/100 = 0.000000573 \text{ degrees/mV}$
 $= 0.0000006 \text{ degrees/mV}$

Low gain resolution : $0.0000573 \text{ degrees}/15 = 0.0000038 \text{ degrees/mV}$
 $= 0.000004 \text{ degrees/mV}$

This high resolution is not achieved for the complete system because of the many system components and due to the non-straight line relationship of the tilt sensor voltage/tilt. It appears justified to use the stated non-linearity deviation of 0.1 degrees for the +/-10 degree range and the 1 degree deviation for the +/-45 degree range as a guide to the potential accuracy to be achieved in the proposed field trial.

Calculation of compression due to rotation from a 45 degree tilt meter housing position, provides the following with the tilt sensor mounted on a 45 degree pedestal so that the tilt sensor X reads 0 = horizontal and the tilt sensor Y reads 0 = horizontal (Figure 1):

RANGE: +/-10 DEGREE (high gain): Error = 0.1 degree

Rotation by $x = 0.1$ degree clock wise will reduce the 45 degree angle to $45 - 0.1 = 44.9$. According to the sketch of Figure 11:

$$B = 47.6 \text{ cm} \times \sin 45^\circ = 33.6583 \text{ cm}$$

$$B1 = 47.6 \text{ cm} \times \sin 44.9^\circ = 33.5995 \text{ cm}$$

Vertical deformation:

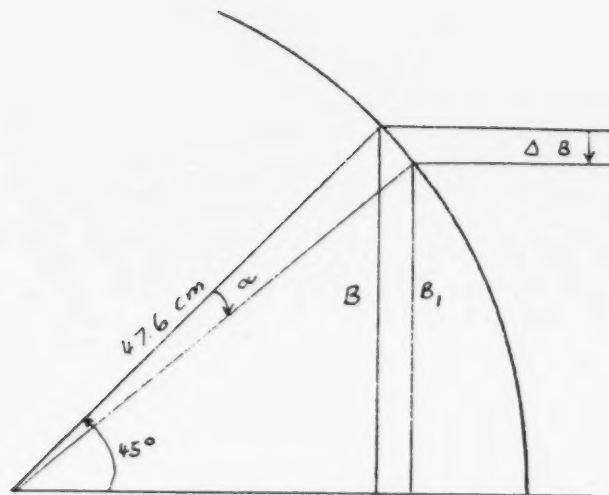
$$B - B1 = 0.0588 \text{ cm}$$

Vertical strain:

$$(B - B1)/B = 0.0588 \text{ cm} / 33.6583 \text{ cm} = 0.001747 \text{ strain}$$

RANGE: +/-45 DEGREE (low gain): Error = 1.0 degree

$$B1 = 47.6 \text{ cm} \times \sin 44^\circ = 33.0657 \text{ cm}$$



$$\Delta B = B - B_1$$

Fig. 11 - Determination of vertical movement from rotation

Vertical deformation:

$$B-B1 = 33.6583\text{cm} - 33.0657\text{cm} = 0.5926\text{cm}$$

Vertical strain:

$$(B-B1)/B = 0.5926/33.6583 = 0.017606 \text{ strain}$$

2.4. Data Acquisition

Data were to be obtained with the 21X data logging system marketed by Campbell Scientific INC. This logging system consists of the following:

Qty

- 1 21X Data Logger with Wiring Panel and 40K RAM
(stores 19,300 data values).
- 1 10 Amp-Hour Rechargeable Instrumentation Batteries.
- 1 020 Enclosure with Alkaline Batteries.
- 1 SM192 Solid-State Storage Module (96,000 data values).
- 1 SC90 9-pin cable and LED monitor.
- 1 SC532 Storage Module - RS232 Interface.
- 1 PC 208 Data Logger Support Software
- 1 DIFFTILT and SINGTILT Data Acquisition Programs.

The use of the data logging system is well documented in the manuals which were supplied with the hardware and are listed in the references. For ease of reference a summary of instructions is provided below.

- 2.4.1. Listing of program CMTL.DLD
- 2.4.2. Download a '.DLD' program from a PC to the 'SM192' module
- 2.4.3. Download a '.DLD' program from the 'SM192' to the 21X datalogger
- 2.4.4. Upload data from the 'SM192' to a '.DAT' data file on the PC
- 2.4.5. Create a '.RPT' report file from a '.DAT' file
- 2.4.6. Set up datalogger and run CMTL.DLD

2.4.1. Listing of program CMTL.DLD

Program: CMTL.DLD
 Flag Usage: OUTPUT PROCESSING
 Analog Input: 2 - 2 COMPONENT TILTMETERS (with temp)
 : EXTERNAL POWER SUPPLY
 : INTERNAL POWER SUPPLY
 : PANEL TEMPERATURE
 Excitation: NONE
 Analog Output: NONE
 Control Port: NONE
 Pulse Input: NONE
 Date Written: FEB. 14/90
 Modified: FEB. 22/90

Input Channel Assignments:

1 - Sensor 544 Axial Tilt - X1
 2 - Sensor 544 Composite Tilt - Y1
 3 - Sensor 544 Temperature - T1
 4 - Sensor 542 Axial Tilt - X2
 5 - Sensor 542 Composite Tilt - Y2
 6 - Sensor 542 Temperature - T2
 7 - Conditioner Power Supply
 8 - Datalogger Power Supply
 9 - Datalogger Temperature

Output Format: 1 - Output Array ID
 2 - Year
 3 - Julian Day
 4 - Hour and Minute (24 hour format)
 5 - Seconds
 6 - X1 (millivolts)
 7 - X1 (degrees)
 8 - Tilt1 (degrees)
 9 - Y1 (millivolts)
 10 - Y1 (degrees)
 11 - T1 (millivolts)
 12 - T1 (deg C)
 13 - X2 (millivolts)
 14 - X2 (degrees)
 15 - Tilt2 (degrees)
 16 - Y2 (millivolts)
 17 - Y2 (degrees)
 18 - T2 (millivolts)
 19 - T2 (deg C)
 20 - Ext P/S (millivolts)
 21 - Ext P/S (volts)
 22 - Int Battery (volts)
 23 - Int Temperature (deg C)

* 1 Table 1 Programs
 01: 5 Sec. Execution Interval (3600 = 1Hr.)
 01: P96 Serial Output
 01: 30 SM192/716

02: P80 Set Active Storage Area
01: 1 Final Storage Area
02: 1 Array ID or location

INCREMENT INTERVAL

03: P32 Z=Z+1
01: 10 Z Loc : Counter - Execution Intervals Into Sample

IF INTERVAL LESS THAN SAMPLE INTERVAL

04: P89 If X<=>F
01: 10 X Loc Execution Intervals Into Sample Interval
02: 4 <
03: 1 F Execution Intervals Between Samples (4@3600 = 4Hr.)
04: 30 Then Do

THEN GO TO END OF PROGRAM

05: P86 Do
01: 0 Go to end of Program Table

ELSE DO THE FOLLOWING

06: P94 Else

ENABLE OUTPUT PROCESSING

07: P86 Do
01: 10 Set flag 0 (output)

READ TIME INTO OUTPUT

08: P77 Real Time
01: 1111 Year, Day, Hour-Minute, Seconds

READ TILTMETER 544

READ X

09: P2 Volt (DIFF)
01: 1 Rep
02: 5 5000 mV slow Range
03: 1 IN Chan X-AXIS
04: 1 Loc : INPUT - X1 (millivolts)
05: 1 Mult
06: 0 Offset

10: P30 Z=F
 01: -48 F
 02: 23 Z Loc : Cal factor (mv/deg)

11: P38 Z=X/Y
 01: 1 X Loc
 02: 23 Y Loc
 03: 11 Z Loc : X1 (degrees from offset)

12: P34 Z=X+F
 01: 11 X Loc
 02: -.2562 F : Apply Offset (degrees)
 03: 11 Z Loc : True X1 (degrees below horizontal)

13: P34 Z=X+F
 01: 11 X Loc
 02: 45 F : Offset of tube from true X1 (degrees)
 03: 21 Z Loc : Presumed tilt of tube (degrees above horzntl)

READ Y

14: P2 Volt (DIFF)
 01: 1 Rep
 02: 5 5000 mV slow Range
 03: 2 IN Chan Y-AXIS
 04: 2 Loc : INPUT - Y1 (millivolts)
 05: 1 Mult
 06: 0 Offset

15: P30 Z=F
 01: -56.77 F
 02: 23 Z Loc : Cal factor (mv/deg)

16: P38 Z=X/Y
 01: 2 X Loc
 02: 23 Y Loc
 03: 12 Z Loc : Y1 (degrees from offset)

17: P34 Z=X+F
 01: 12 X Loc
 02: .16183 F : Apply Offset (degrees)
 03: 12 Z Loc : True Y1 (degrees below horizontal)

READ TEMPERATURE

18: P2 Volt (DIFF)
 01: 1 Rep
 02: 4 500 mV slow Range
 03: 3 IN Chan TEMP
 04: 3 Loc : INPUT - T1 (millivolts)
 05: 1 Mult
 06: 0.0000 Offset

19: P37 Z=X*F
01: 3 X Loc
02: .1 F : Cal Factor (degrees C/mv)
03: 13 Z Loc : T1 (degrees C)

READ TILTMETER 542

READ X

20: P2 Volt (DIFF)
01: 1 Rep
02: 5 5000 mV slow Range
03: 4 IN Chan
04: 4 Loc : INPUT - X2 (millivolts)
05: 1 Mult
06: 0 Offset

21: P30 Z=F
01: -61.651 F
02: 23 Z Loc : Cal Factor (mv/deg)

22: P38 Z=X/Y
01: 4 X Loc
02: 23 Y Loc
03: 14 Z Loc : X2 (degrees from offset)

23: P34 Z=X+F
01: 14 X Loc
02: .04644 F : Apply Offset (degrees)
03: 14 Z Loc : True X2 (degrees below horizontal)

24: P34 Z=X+F
01: 14 X Loc
02: 45 F : Offset of tube from true X1 (degrees)
03: 24 Z Loc : Presumed tilt of tube (degrees above horzntl)

READ Y

25: P2 Volt (DIFF)
01: 1 Rep
02: 5 5000 mV slow Range
03: 5 IN Chan
04: 5 Loc : INPUT Y2
05: 1 Mult
06: 0 Offset

26: P30 Z=F
01: -72.542 F
02: 23 Z Loc : Cal factor (mv/deg)

27: P38 Z=X/Y
01: 5 X Loc
02: 23 Y Loc
03: 15 Z Loc : Y2 (degrees from offset)

28: P34 Z=X+F
01: 15 X Loc
02: -.00193 F : Apply Offset (degrees)
03: 15 Z Loc : Y2 (degrees below horizontal)

READ TEMPERATURE

29: P2 Volt (DIFF)
01: 1 Rep
02: 4 500 mV slow Range
03: 6 IN Chan
04: 6 Loc : INPUT T2 millivolts
05: 1 Mult
06: 0 Offset

30: P37 Z=X*F
01: 6 X Loc
02: .1 F : Cal Factor (deg C/mv)
03: 16 Z Loc : T2 (degrees C from offset)

31: P34 Z=X+F
01: 16 X Loc
02: -4.67 F : Apply Offset (deg C)
03: 16 Z Loc : T2 (degrees C)

READ JUNCTION BOX POWER SUPPLY

32: P2 Volt (DIFF)
01: 1 Rep
02: 5 5000 mV slow Range
03: 7 IN Chan
04: 7 Loc : INPUT - External P/S (millivolts)
05: 1 Mult
06: 0 Offset

33: P37 Z=X*F
01: 7 X Loc
02: 4.265 F : Divider Cal Factor (mv/mv)
03: 17 Z Loc : External P/S (millivolts)

34: P37 Z=X*F
01: 17 X Loc
02: .001 F : Unit Conversion Factor (V/mv)
03: 17 Z Loc : External P/S (volts)

READ DATALOGGER BATTERY VOLTAGE

35: P10 Battery Voltage
01: 8 Loc : INPUT - Internal Battery (volts)

INPUT LOGGER TEMPERATURE

36: P17 Panel Temperature
01: 9 Loc : INPUT - Datalogger Temperature (degrees C)

OUTPUT DATA

37: P78 Resolution
01: 1 High Resolution

38: P70 Sample
01: 1 Rep
02: 1 Loc : X1 (millivolts)

39: P70 Sample
01: 1 Rep
02: 11 Loc : True X1 (degrees below horizontal)

40: P70 Sample
01: 1 Rep
02: 21 Loc : Presumed Tube Tilt (degrees above horizontal)

41: P70 Sample
01: 1 Rep
02: 2 Loc : Y1 (millivolts)

42: P70 Sample
01: 1 Rep
02: 12 Loc : True Y1 (degrees below horizontal)

43: P70 Sample
01: 1 Rep
02: 3 Loc : T1 (millivolts)

44: P78 Resolution
01: 0 Low Resolution

45: P70 Sample
01: 1 Rep
02: 13 Loc : T1 (degrees C)

46: P78 Resolution
01: 1 High Resolution

47: P70 Sample
01: 1 Rep
02: 4 Loc : X2 (millivolts)

48: P70 Sample
01: 1 Rep
02: 14 Loc : True X2 (degrees below horizontal)

49: P70 Sample
01: 1 Rep
02: 24 Loc : Presumed Tube Tilt (degrees above horizontal)

50: P70 Sample
 01: 1 Rep
 02: 5 Loc : Y2 (millivolts)

51: P70 Sample
 01: 1 Rep
 02: 15 Loc : True Y2 (degrees below horizontal)

52: P70 Sample
 01: 1 Rep
 02: 6 Loc : T2 (millivolts)

53: P78 Resolution
 01: 0 Low Resolution

54: P70 Sample
 01: 1 Rep
 02: 16 Loc : T2 (degrees C)

55: P78 Resolution
 01: 1 High Resolution

56: P70 Sample
 01: 1 Rep
 02: 7 Loc : External P/S (millivolts)

57: P78 Resolution
 01: 0 Low Resolution

58: P70 Sample
 01: 1 Rep
 02: 17 Loc : External P/S (volts)

59: P78 Resolution
 01: 0 Low Resolution

60: P70 Sample
 01: 1 Rep
 02: 8 Loc : Internal Battery (volts)

61: P70 Sample
 01: 1 Rep
 02: 9 Loc : Datalogger Panel Temperature

RESET EXECUTION INTERVAL COUNTER

62: P30 Z=F
 01: 0 F
 02: 10 Z Loc : RESET EXECUTION INTERVAL COUNTER

DISABLE OUTPUT PRINTING

63: P86 Do
 01: 20 Reset flag 0 (output)

END ELSE

64: F95 End

65: F End Table 1

* 2 Table 2 Programs
01: 0.0000 Sec. Execution Interval

01: F End Table 2

* 3 Table 3 Subroutines

01: F End Table 3

* 4 Mode 4 Output Options
01: 00 Tape/Printer Option
02: 00 Printer Baud Option

* A Mode 10 Memory Allocation
01: 29 Input Locations
02: 64 Intermediate Locations

* C Mode 12 Security (OSX-0)
01: 00 Security Option
02: 0000 Security Code

Page 9 Input Location Assignments (with comments):

Key:

T=Table Number

E=Entry Number

L=Location Number

T.	E.	L.	
1:	9:	1:	Loc : INPUT - X1 (millivolts)
1:	14:	2:	Loc : INPUT - Y1 (millivolts)
1:	18:	3:	Loc : INPUT - T1 (millivolts)
1:	20:	4:	Loc : INPUT - X2 (millivolts)
1:	25:	5:	Loc : INPUT Y2
1:	29:	6:	Loc : INPUT T2 millivolts
1:	32:	7:	Loc : INPUT - External P/S (millivolts)
1:	35:	8:	Loc : INPUT - Internal Battery (volts)
1:	36:	9:	Loc : INPUT - Datalogger Temperature (degrees C)
1:	3:	10:	Z Loc : Counter - Execution Intervals Into Sample
1:	62:	10:	Z Loc : RESET EXECUTION INTERVAL COUNTER
1:	11:	11:	Z Loc : X1 (degrees from offset)
1:	12:	11:	Z Loc : True X1 (degrees below horizontal)
1:	16:	12:	Z Loc : Y1 (degrees from offset)
1:	17:	12:	Z Loc : True Y1 (degrees below horizontal)
1:	19:	13:	Z Loc : T1 (degrees C)
1:	22:	14:	Z Loc : X2 (degrees from offset)
1:	23:	14:	Z Loc : True X2 (degrees below horizontal)
1:	27:	15:	Z Loc : Y2 (degrees from offset)
1:	28:	15:	Z Loc : Y2 (degrees below horizontal)
1:	30:	16:	Z Loc : T2 (degrees C from offset)
1:	31:	16:	Z Loc : T2 (degrees C)
1:	33:	17:	Z Loc : External P/S (millivolts)
1:	34:	17:	Z Loc : External P/S (volts)
1:	13:	21:	Z Loc : Presumed tilt of tube (degrees above horzntl)
1:	10:	23:	Z Loc : Cal factor (mv/deg)
1:	15:	23:	Z Loc : Cal factor (mv/deg)
1:	21:	23:	Z Loc : Cal Factor (mv/deg)
1:	26:	23:	Z Loc : Cal factor (mv/deg)
1:	24:	24:	Z Loc : Presumed tilt of tube (degrees above horzntl)

2.4.2. Download a '.DLD' program rom a PC to the 'SM192' module

PURPOSE: to download a 'FC 208 .DLD' (21X Micrologger) program
from an IBM PC (or compatible) to the 'SM192' storage module via
the 'SC532' interface

Computer Prompts -----	Operator Enters -----	Comment -----
\DATALOGG>	SMCOM[return]	enter SMCOM from system
Serial Port Options:		
1 -- Com1		
2 -- Com2		
3 -- Com3		
4 -- Com4		
Option:	1	Com 1 used at CMTL
Is the SM232 or SM232A interface being used? (Y/N):		
	N	not part of CMTL equip
Root collection file name (6 characters max):		
	CMTL[return]	for CMTL basic program
SMCOM Ver 3.2 Options:		
T -- Terminal emulator.		
A -- Collect all data files.		
U -- Collect uncollected data files.		
M -- Collect last 5 data files.		
N -- Collect newest data file.		
L -- Collect one data file starting at display pointer.		
P -- Collect program files.		
D -- Store a .DLD program file.		
F -- Store a file.		
Q -- Quit		
Option:	D	
Enter the .DLD file name (#1..#8 optional prefix):		
	CMTL[return]	
SMCOM Ver 3.2 Options	Q	return to system level
\DATALOGG>		

2.4.3. Download a '.DLD' program from the 'SM192' to the 21X datalogger

PURPOSE: to download a 'PC 200 .DLD' (21X Micrologger) program from the 'SM192' storage module to the 21X datalogger

Datalogger Prompts -----	Operator Enters -----	Comment -----
anything	*D	as a sequence (all instructions) assumes logger not just turned on and time is set
13:00	71A	select 'Save/Load Program' command
71:00	21A	program #1 from storage module
7121		loading and compiling
13:0000		program running

Note: Leave 'SM192' connected. This will allow enough storage for 1 sample every four hours for 1 year. Without the 'SM192' only 12 days of data can be stored in the 21X ring buffer i.e. overwrites old data.

Enter new root file name
Root collection file name (6 Characters max):
CMTL

Writing to computer file CMTL02.DAT

SMCOM Ver 3.2 Options:

- T -- Terminal emulator.
- A -- Collect all data files.
- U -- Collect uncollected data files.
- M -- Collect last 5 data files.
- N -- Collect newest data file.
- L -- Collect one data file starting at display pointer.
- P -- Collect program files.
- D -- Store a .DLD program file.
- F -- Store a file.
- Q -- Quit

Option: Q

\DATALOGG>

2.4.4. Upload data from the 'SM192' to a '.DAT' file in the PC

PURPOSE: to retrieve data from the 21X datalogger via the 'SM192' storage via the 'SC532' interface and store it in a '.DAT' file in an IBM PC (or compatible).

Note: Retrieve the 'SM192' from the datalogger
Connect the nine pin connector to the 'SC532'
connect the 'SC532' to Com1 on the computer

Computer Prompts -----	Operator Enters -----	Comment -----
\DATALOGG>	SMCOM[return]	enter SMCOM from system
Serial Port Options:		
1 -- Com1		
2 -- Com2		
3 -- Com3		
4 -- Com4		
Option:	1	Com 1 used at CMTL
Is the SM232 or SM232A interface being used? (Y/N):	N	not part of CMTL equip
Root collection file name (6 characters max):	CMTL[return]	for CMTL basic program
SMCOM Ver 3.2 Options:		
T -- Terminal emulator.		
A -- Collect all data files.		
U -- Collect uncollected data files.		
M -- Collect last 5 data files.		
N -- Collect newest data file.		
L -- Collect one data file starting at display pointer.		
P -- Collect program files.		
D -- Store a .DLD program file.		
F -- Store a file.		
Q -- Quit		
Option:	N	
cmt101.dat is empty		
File Formats		
F -- Final Storage (FS) format		
D -- FS converted to ASCII arrays with IDs		
C -- FS converted to comma delineated ASCII arrays		
A -- As stored (8 bit data)		
P -- As stored but ignore parity bit		
ESC -- Escape		
Format:	D	
CMTL.DAT already exists!		

Name of parameter file (* = help): CMTLALL

now in edit mode for CMTLALL F2

'Function 2' Key

Edit Run Save Quit Load new parameter file
R

screen displays report being generated as above

Edit Run Save Quit Load new parameter file
Q

\DATALOGG> print cmtlrpt.rpt

report is printed

\DATALOGG> print cmtlall.rpt if needed

\DATALOGG>

2.4.5. Create a '.RPT' report file from a '.DAT' file

PURPOSE: to create and print a '.RPT' printable report file from a '.DAT' data file recovered from the 'SM192' storage module. Two parameter files exist for these files (CMTLALL, CMTLRPT).

'CMTLALL' will produce 'CMTLALL.RPT' which contains all the data collected by 'CMTL.DLD' (including raw millivolts) but prints wider than 15inch i.e. returns to right for last few columns.

'CMTLRPT' will produce a more presentable report, (CMTLRPT.RPT), without raw data.

Both files will produce a report on 11x15 inch computer paper.

Note: connect the 'SC532' nine pin connector to the 'SM192' storage module
connect the 'SC532' to Com 1 of the computer

Computer Prompts -----	Operator Enters -----	Comment -----
\DATALOGG>	SPLIT{return}	enter SPLIT from system
Serial Port Options:		
1 -- Com1		
2 -- Com2		
3 -- Com3		
4 -- Com4		
Option:	1	Com 1 used at CMTL
Is the SM232 or SM232A interface being used? (Y/N):	N	not part of CMTL equip
Root collection file name (6 characters max):	CMTL{return}	for CMTL basic program
Split Version 4.4 (editor screen) F2		'Function 2' Key
Edit Run Save Quit Load new parameter file L		
Name of parameter file (* = help): CMTLRPT		
now in edit mode for CMTLRPT F2		'Function 2' Key
Edit Run Save Quit Load new parameter file R		
screen displays report being generated hit 'Pause/Break' to freeze screen then any key to continue		
Edit Run Save Quit Load new parameter file L		

2.4.6 Set up datalogger and run CMTL.DLD

- 1 - press '' and then '5' on the datalogger which should respond with the time in the format ':HH:MM:SS'
- 2 - press 'A' and the datalogger will display 89 as in 1989.
- 3 - press '90A' as in 1990 and the logger displays 05:0090.
- 4 - enter the Julian day from the '21X Prompt Sheet', press 'A' and the logger displays 05:0XXX,XXX as Julian day.
- 5 - enter the time in the 24 hour format ':HH:MM', press 'A' and the logger displays 05:HH:MM:SS.

To commence running the program 'CMTL.DLD' stored in the 'SM192' storage module (stainless steel tin):

- 1 - press '' and then 'D' on the datalogger which should respond with '13:00'
- 2 - press '7', then '1', then 'A', and the datalogger should respond with '7:00'.
- 3 - press '2', then '1', then 'A', and the datalogger should respond with '7121' and after a few seconds display '13:0000'

The present version of program CMTL.DLD takes samples every four hours and for a period of six months.

3. REFERENCES

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APPENDIX C

CANMET REPORT ON CONSOLIDATION METER DESIGN

**A CONSOLIDATION METER FOR MEASURING COMPACTION
IN SALT WASTE BACKFILL**

K. Judge and G. Herget

Canadian Mine Technology Laboratory

MRL 90-042(TR)

May 1990

A CONSOLIDATION METER FOR MEASURING COMPACTION
IN SALT WASTE BACKFILL

K. Judge* and G. Herget**

SUMMARY

A borehole consolidation meter has recently been designed and constructed at the Canadian Mining Technology Laboratory (CMTL) to monitor consolidation in waste salt backfill. The meter was designed to be installed in a downward vertical six inch diameter hole and provide a simple means of monitoring compaction due to traffic, continued backfilling and recrystallisation. Seven such monitors have been built and installed at the Potash Company of America Potash mine, Sussex, New Brunswick. The report describes the instrument and provides calibration information.

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Keywords: consolidation meter, backfill, potash

DESIGN

Figure 1 shows the assembly of the consolidation meter and a photograph of the assembled unit. The sensor is a 20K ohm linear plunger type potentiometer with a nominal four inch travel. More detailed information is given in figures 2 through 6.

The potentiometer is suspended from the top of a bore hole via an eight inch plywood disk. This disk is bolted on with a 5/8 in. coarse left hand threaded bolt, nut and two heavy washers. The plunger is connected to an extension sleeve and enclosed in a plunger sleeve.

The sleeves are made of nominal 3/4 in. and 1 in. copper water pipe. A special slider sleeve and O-ring seal was made (Figure 5) to resist water and other foreign material entering the potentiometer housing. A rubber grommet is used to pass the signal cable through the plunger sleeve and seal it. The bottom end of the extension sleeve is centred and held in the bore hole by a five inch diameter plywood disk which is buried in backfill. This disk is pinned between two heavy washers using two hitch pins. These pins facilitate rapid assembly in the mine environment. A parts list is given in table 1. (numbers correspond to figure 1.)

For shipping the meters are compressed to five feet with the plywood disks removed. The plywood disks have been finished with two coats of linseed oil and two coats of oil based paint to prevent delamination.

Figure 7 shows a typical calibration which is almost a straight line over 110 mm.

L.H.T. Rod 3

L.H.T. Nut 2

LEAD CABLE

RUBBER BUSHING 6

POTENTIOMETER HOUSING 5

WASHER 3

LONGER HOUSING 7

SLIDER SLEEVE 8

EXTENSION SLEEVE 9

LARGE WASHER 10

NUT PIN 12

LARGE PLYWOOD DISK 4

SMALL PLYWOOD DISK 11

FIGURE 1 - GROUND MOVEMENT MONITOR
MODEL B-GM22
ASSEMBLY DRAWING

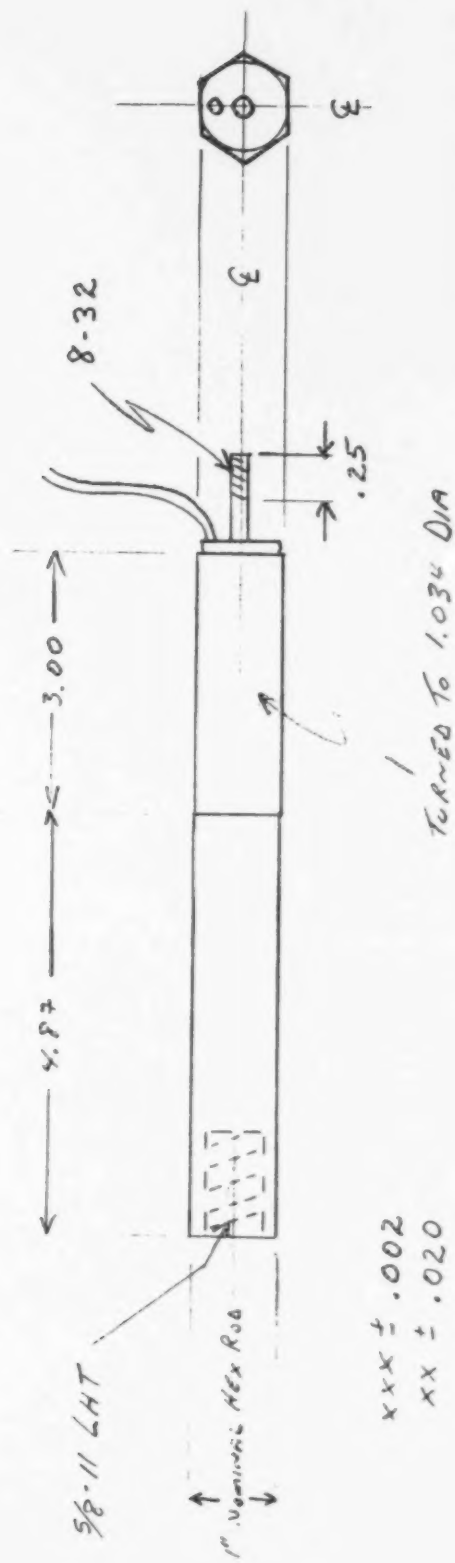
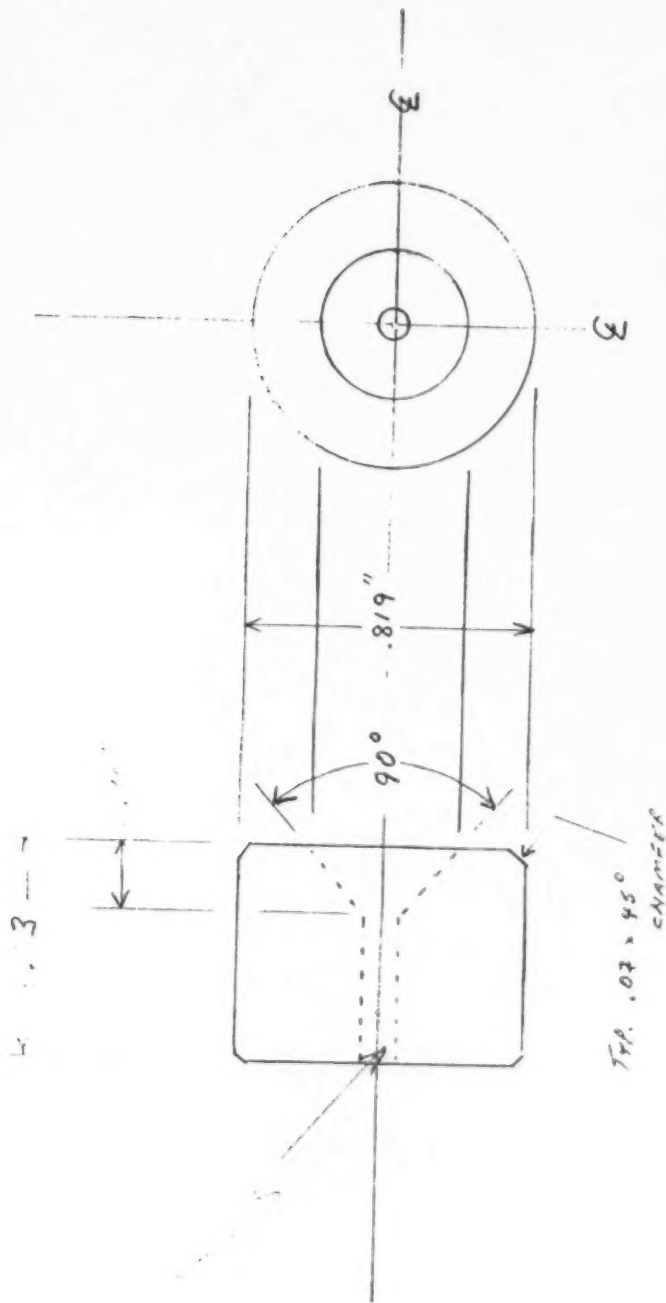


FIGURE 2 - POTENTIOMETER HOUSING DETAIL
MODEL B-GM22



MATERIAL: BRASS

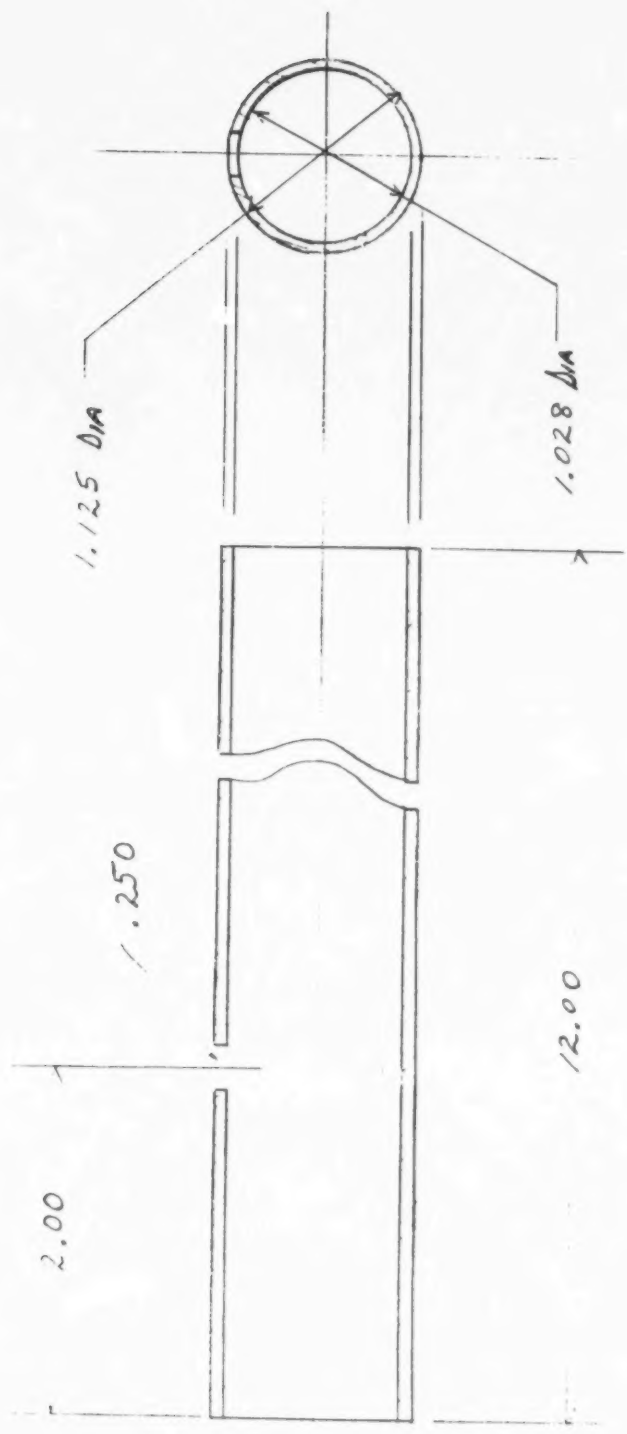
FIGURE 3 - PLUNGER/EXTENSION ADAPTER
MODEL B-GM22

X X X ± .001

X X ± .020

NOTE: ALL DIMENSIONS IN INCHES

DRILL + TAP
8-32

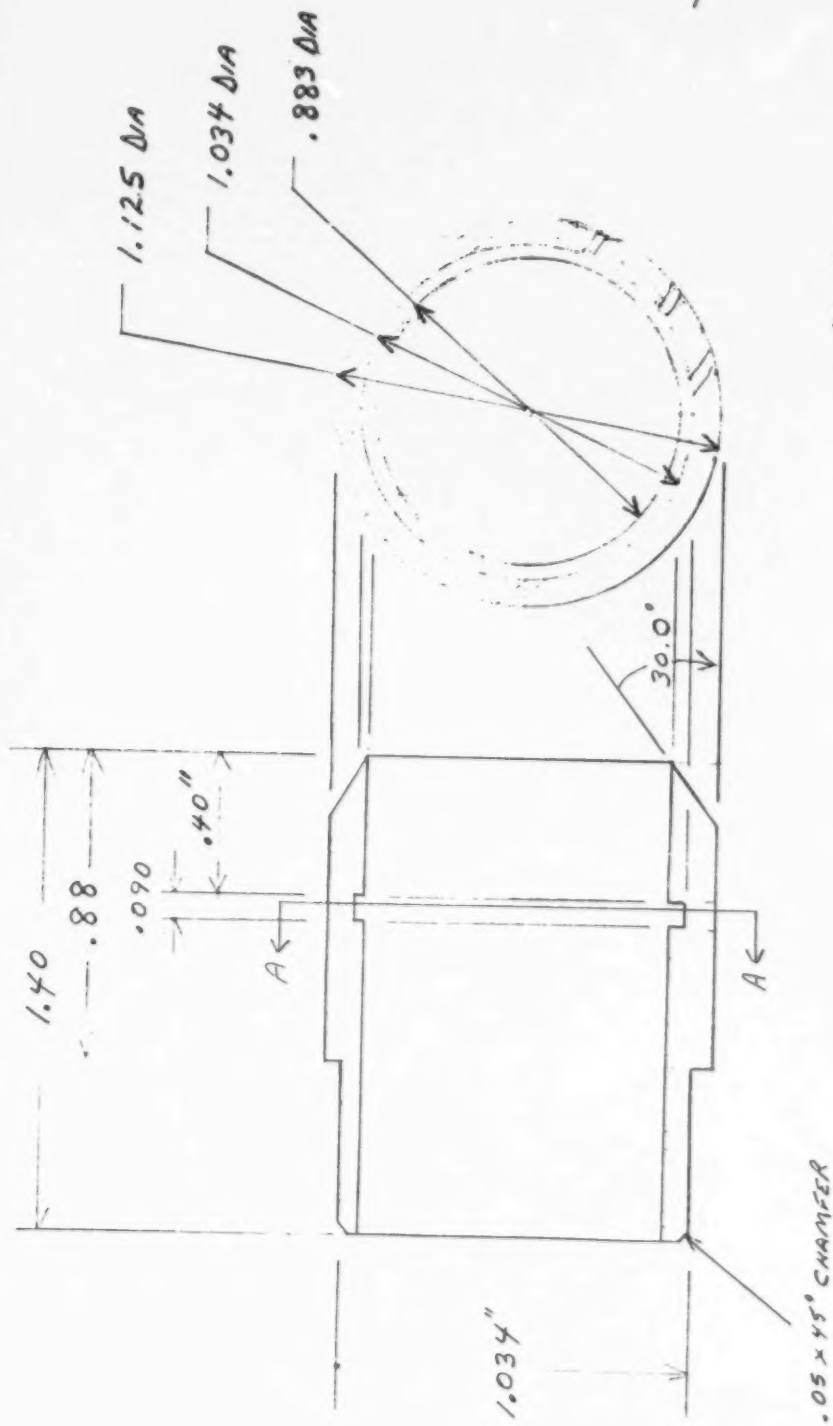


MATERIAL: 1" Nominal Copper
WATER PIPE

Notes: Lines are Snap Centers
.005 x 45° Chamfered Ends
All Dimensions in Inches

X X X ± .005
X X X ± .05

FIGURE 4 - Plunger Housing Detail
MOORE B-GM22



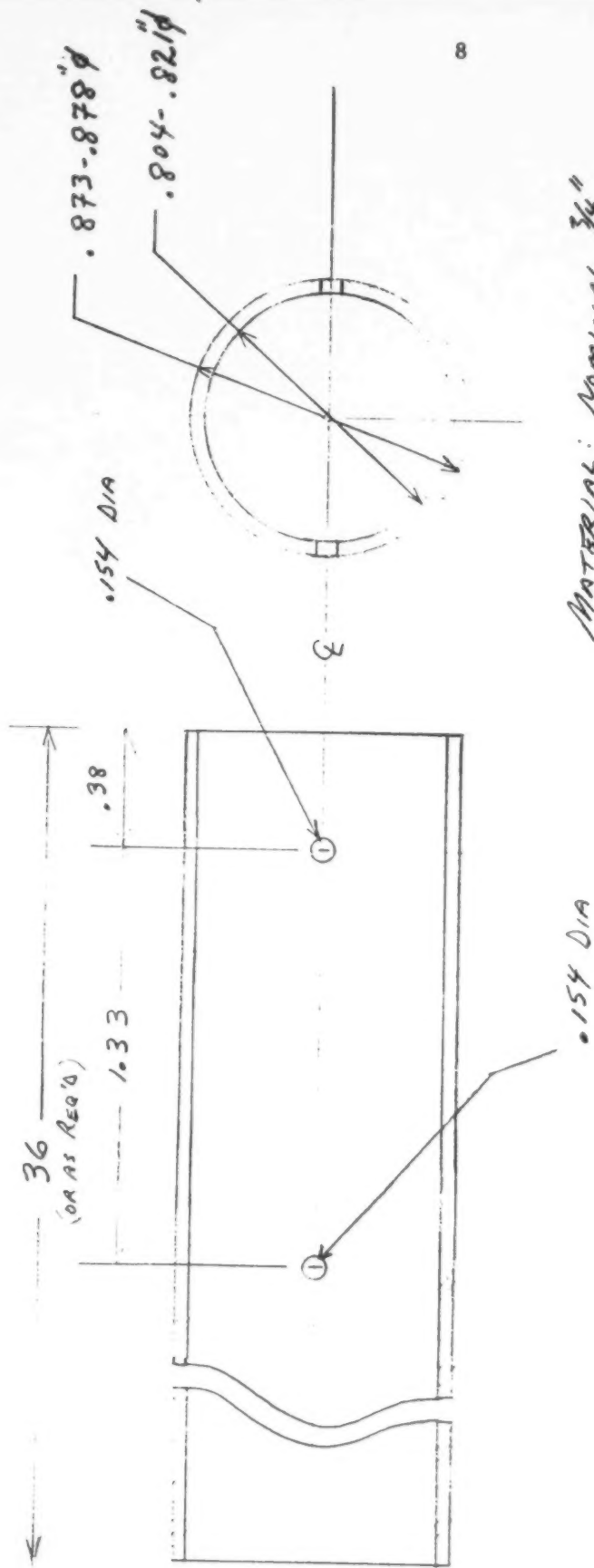
SECTION "AA"

MATERIAL: DELRIN

FIGURE 5 - SLIDER SUBASSEMBLY
MODEL B-GM22

XXX ± .001
XX ± .020

NOTE: ALL DIMENSIONS IN INCHES



8

MATERIAL: NOMINAL $\frac{3}{4}$ "
COPPER WATER PIPE

XXX - NOMINAL PIPE (OBS. RANGE)
 .XX ± .01"
 XX ± .1"

NOTE: ALL DIMENSIONS IN INCHES
 FIGURE 6 - EXTENSION SLEEVE DETAIL
 MODEL B-GM22

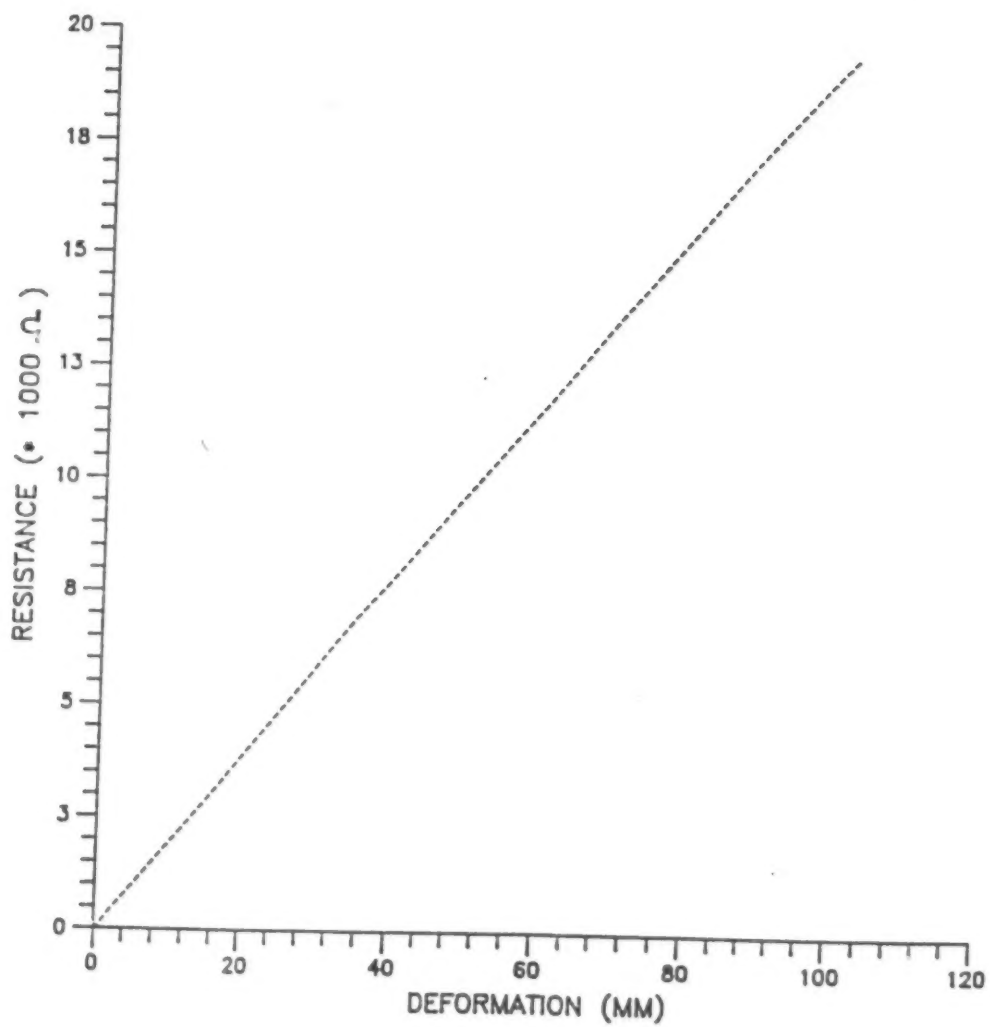


Fig. 7 - Calibration for the 4m (10cm) potentiometer

Table 1: Components of consolidation meter

- 1) 2 1/2" X 5/8" - 11 NC left hand threaded rod
- 2) 5/8" - 11 NC left hand threaded nut
- 3) 5/8" U.S.S. flat washer (2 required)
- 4) 8" O.D. X 5/8" I.D. X 3/4" G2S plywood (linseed oil & paint)
- 5) 20K ohm linear potentiometer in 1" hex rod, 25 ft. cable
- 6) 1/4" O.D. (plus flange) X 3/16" I.D. rubber bushing
- 7) 12" X 1" dia. copper water pipe
not shown: brass plunger / extension adapter
- 8) nylon sleeve and O-ring
- 9) 36" X 3/4" dia. copper water pipe
- 10) 5" O.D. X 7/8" I.D. 3/4" G2S plywood (linseed oil & paint)
- 11) 7/8" U.S.S. flat washer (2 required)
- 12) #9 hitch pin (2 required)